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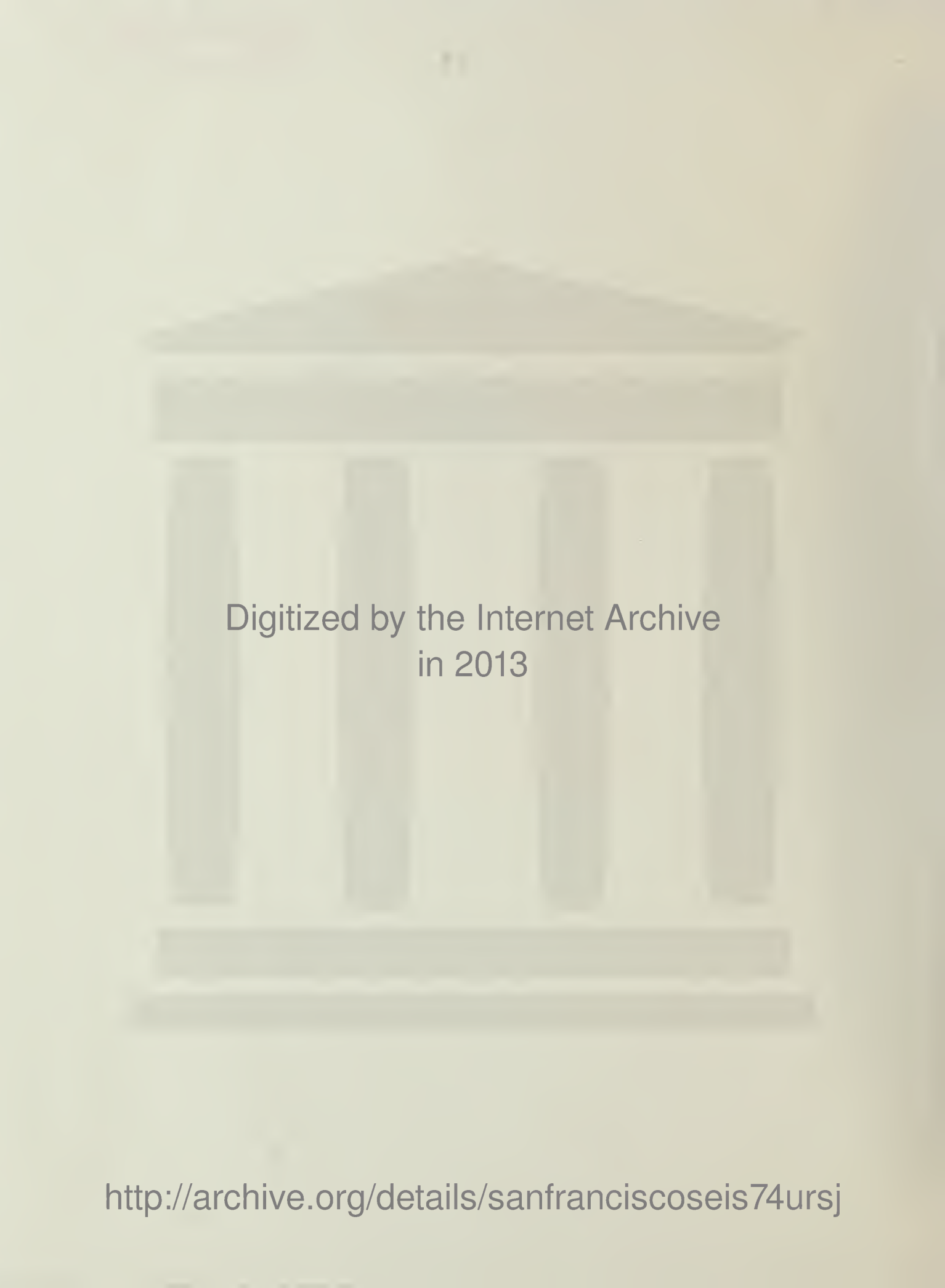
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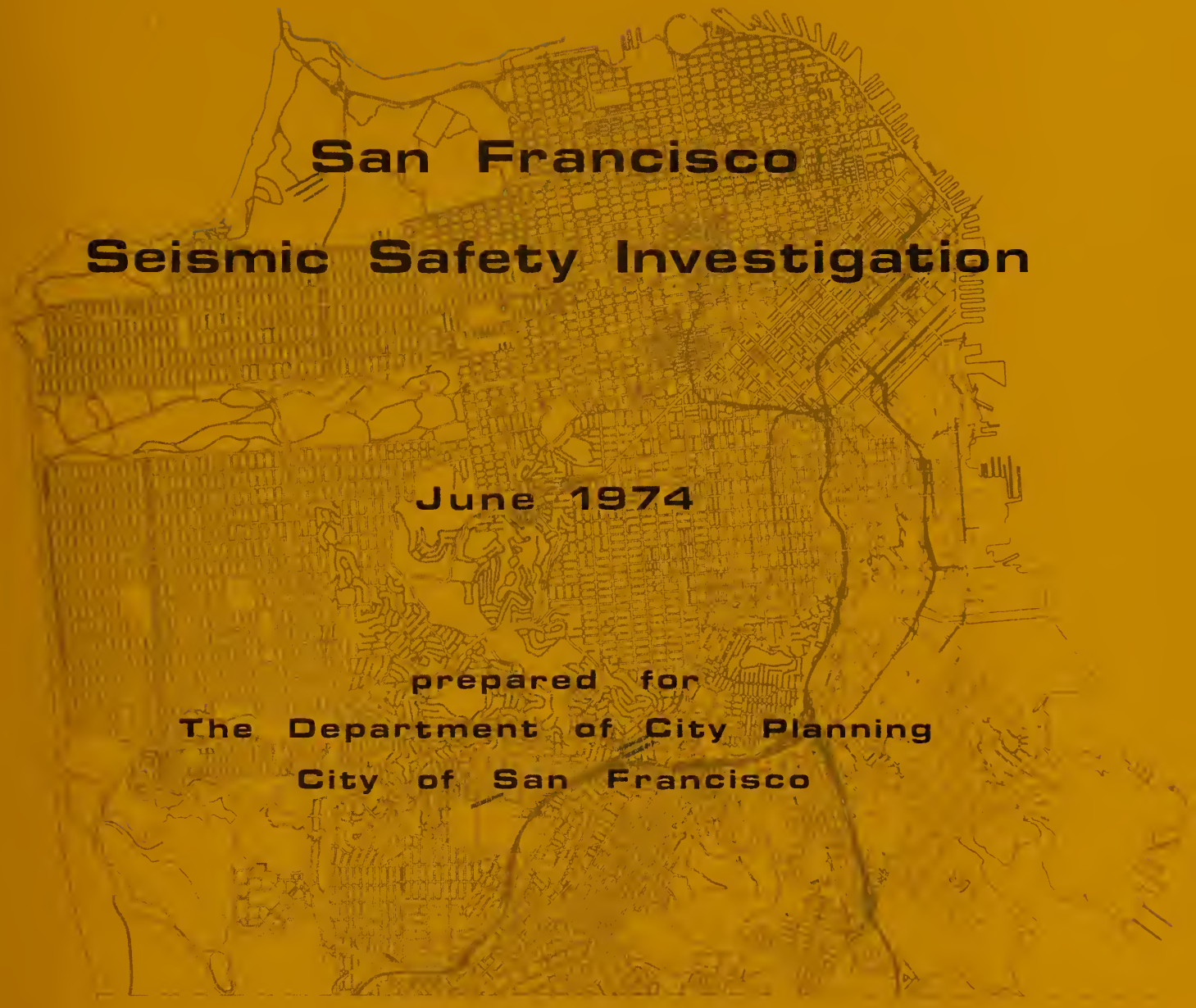

San Francisco

Seismic Safety Investigation

June 1974

prepared for

The Department of City Planning

City of San Francisco

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SAN FRANCISCO SEISMIC SAFETY INVESTIGATION

prepared for

The Department of City Planning
City of San Francisco

June 1974

by

URS/John A. Blume & Associates, Engineers
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PREFACE

The disastrous San Fernando earthquake of 1971 was followed by increased concern over the seismic safety of other communities in California. In response, the State of California passed legislation requiring cities to consider seismic hazards to life and property within their bounds. The study reported herein is part of the City of San Francisco's response to the new legislation.

This report consists of two parts -- Part I: Geologic Evaluation and Part II: Structural Evaluation.

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PURPOSE

This report summarizes the work of two seismic studies of the City of San Francisco conducted by URS/John A. Blume & Associates, Engineers, (JAB) for the Department of City Planning. The studies consisted of a geologic evaluation and a structural evaluation of earthquake hazards within the city. Principal output from these studies consists of the identification of the major geologic and structural hazards that are summarized in a series of maps delineating where in the city these hazards are believed to exist. Results of this study will aid in minimizing future loss of life and economic loss due to earthquakes through disaster-mitigation procedures and future land-use planning.

Impetus for these investigations was given by recent state legislation SB 1489, which requires California cities to include a Seismic Safety Element in their comprehensive city plans. The burden for the implementation of this legislation for the city of San Francisco rests with the Department of City Planning which, in turn, retained this firm to provide consulting services in the geologic hazard and structural engineering areas.

MAJOR FINDINGS

The studies resulted in the identification and evaluation of earthquake hazards in the city of San Francisco. Foremost among these hazards are building damage and resulting casualties from ground shaking. Although there is no indication of active faults within the city limits, the city is in close proximity to the San Andreas fault, which caused the 1906 disaster. In addition, there are other faults east of the bay that could cause damage in San Francisco.

There are other hazards, for example, from potentially unstable ground under earthquake conditions. Such hazards as liquefaction, subsidence, and tsunami inundation exist along areas of the eastern and northern waterfronts, and a liquefaction hazard also exists in the Lake Merced area. Landslides are a hazard in certain hilly regions. These and other hazards such as flooding from reservoirs are described in "Part I: Geologic Evaluation."

Economic loss, injuries, and fatalities are expected to result from damage to structures, mainly buildings. While large areas of the city would be expected to experience only moderate or slight building damage, the study revealed that some areas have a relatively high concentration of buildings of a type with a well-established record of poor earthquake performance. Some of these buildings may be expected to experience partial or even complete collapse, particularly some of the pre-code, unreinforced masonry structures. In the downtown area, there are also potential hazards from falling parapets, cornices, ornamentations, and glass. "Part II: Structural Evaluation" describes these hazards.

Buildings built since San Francisco's first seismic building code of 1948 are generally much better risks than those built before 1948. Modern engineering and earth science technology together with earthquake building code provisions and city planning can greatly reduce, and in many cases eliminate, earthquake hazards.

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The study also determined that San Francisco's vital utility and transportation lifelines and the emergency services of fire, police, health, and emergency communications generally need improved seismic planning and design. Emergency services, in particular, may be vulnerable to complete or partial loss of the usefulness of some of their physical facilities for the vital period immediately after a major earthquake.

ACKNOWLEDGMENTS

Various members of URS/John A. Blume & Associates, Engineers, participated in this study. The overall program was under the direction of Dr. John A. Blume. Ronald Gallagher served as program manager.

The Geologic Evaluation was prepared by Andrew B. Cunningham, Senior Engineering Geologist, assisted by Bruce Auld, Engineering Seismologist, and Dr. C. K. Chen, Engineering Hydrologist.

The Structural Evaluation was prepared by John A. Blume with assistance from Bing Mah, Structural Engineer, and Kenneth Schopp, Manager of Computer Technology.

Throughout the course of the study, enthusiastic assistance was provided by members of the Department of City Planning. We are also indebted to those in the Bureau of Building Inspection, Department of Public Works, City Engineer's Office, City Architect's Office, City Assessor's Office, State of California Division of Mines and Geology, and U.S. Geological Survey for their assistance in providing data.

PART I

GEOLOGIC EVALUATION

INTRODUCTION TO PART I

Part I of this report describes results of a study conducted by URS/ John A. Blume & Associates, Engineers, to identify, describe, and evaluate geologic and seismologic factors of earthquake hazards within the city and county of San Francisco. This work was carried out for the Department of City Planning of San Francisco under contract to the City of San Francisco.

Information considered appropriate to the general purposes of the study was selected from published and unpublished investigations performed by government agencies, private firms, and individuals. Although these data should be regarded as generally applicable and dependable, confirmation of their accuracy or reliability was not within the scope of this report.

Information is presented in this report primarily in the form of maps. In most instances these have been compiled separately, each dealing with a different geologic hazard, so as to avoid possible confusion in their interpretation. The scale of these is 1 inch equals 1500 feet, but many of the source maps from which information was obtained were on much smaller scales and were therefore of relatively lower accuracy.

The geologic hazard maps should be modified as new information is acquired or published. Because those maps showing hazard areas due to liquefaction and subsidence are intended to be conservative, new information will in most instances result in diminishing the size of the hazard area. There is a large amount of information in unpublished reports, not available for this study, which might be gradually incorporated into the maps.

The maps and text of this report are intended to provide a basis for estimating present earthquake hazards to people, buildings, and facilities and to minimize earthquake hazards in future development. The

data presented herein do not supplant the detailed geotechnical data normally acquired prior to land development or building design.

Part I first presents and discusses various geologic hazards. The last chapter deals with the impact of these geologic hazards on land-use policy.

GEOLOGIC MAP OF SAN FRANCISCO

General Statement

Earthquake damage to man-made structures may result from intense shaking or from soil and rock failures that in turn cause structural damage. Such damage may also be caused by differential ground movement on opposite sides of a fault. The intensity of earthquake shaking is strongly influenced by the type of soil or rock underlying an area, and the possibility of ground failure is primarily determined by the soil and rock types present. The location of faults that might move during an earthquake defines the possible hazard due to surface rupture.

A geologic map showing areal distribution of soil and rock types and fault locations is an important aid to the evaluation of earthquake hazards. The formations shown on the geologic map are described on the map. Their engineering properties, susceptibility to earthquake failure, and type of failure are discussed in the following pages. Detailed discussion of specific hazards such as landsliding, liquefaction, and fault rupture are presented elsewhere in this report.

The generalized geologic map (Figure 1) of San Francisco was abstracted from work by Schlocker, et al. (1958) and Bonilla (1971). The accuracy and reliability of this work was not confirmed by JAB and this map is not intended to supplant detailed geologic and soils investigations of specific sites that may be required by building codes, by other ordinances, or by the principles of good engineering practice.

To better achieve the purpose of providing a basis for evaluation of seismic hazard the geologic map has been simplified. Certain soil and rock types with different geologic properties have been combined into the same formation or map unit because they have similar engineering properties. Small outcrop areas were often simplified or omitted. No field work was done to compile Figure 1.

The geologic map shows the location and areal extent of the major geologic formations in San Francisco that have distinctive engineering characteristics. When possible, it also shows such geologic structures as folds, faults, and attitude of bedding.

Earthquake Stability of Geologic Formations

Artificial Fill (Qaf). The stability of artificial fill varies. Modern fills placed on firm ground and properly compacted have good stability and often are at least as resistant to earthquake failure as is adjacent natural ground. Fills placed many years ago over soft bay muds without compaction are very susceptible to failure under earthquake forces. Most of the low marshlands bordering the bay within the city of San Francisco were filled many years ago and constitute relatively large areas with a high susceptibility to earthquake-generated soil failure. During the 1906 earthquake, these areas displayed such effects of severe disturbance as buckling of the ground surface, fissuring, cracking, bending of rails, and subsidence. These effects were caused by failure of the soft bay muds and loose sands lying at some depth beneath the ground surface. Some localized areas of artificial fill that were not placed on bay mud also failed in the 1906 earthquake, but these were not extensive.

Filled ground within the western part of the city underlain by sand dune deposits should have fair stability under earthquake conditions. However, if the underlying sand deposits are saturated near the ground surface and are of medium or low density, they may be susceptible to liquefaction.

Aside from filled areas on marshland, most of the artificial fills in San Francisco are fairly resistant to earthquake-generated soil failure. Good quality fills consisting of well-compacted fill material on a firm base have good stability.

Landslide Deposits (Ql). Landslides may be considered a normal part of the geologic cycle by which uplifted lands are eroded. They typically

occur under static conditions when the gravitational forces exerted on a mass of soil or rock become greater than those supporting it. The weakening of support beneath a land mass may occur naturally or through human acts. A land mass that has already undergone sliding or that is very weakly supported may slide if the additional forces of earthquake ground motions act on it. The known landslide areas in San Francisco are indicated in Figure 1. Landslides are also discussed more extensively later in this report, where a more comprehensive map showing only landslide locations is examined.

Beach Deposits (Qrb). Beach deposits consisting predominantly of clean sand are found along the western margin of the city facing the ocean and in some small embayments around the northern portion of the peninsula. Beach deposits have a high susceptibility to earthquake damage because of the relatively high potential for liquefaction in the saturated sands beneath the ground surface. Although they may appear to be unaffected in their natural state by strong earthquakes, a heavy structure placed upon them may suffer a loss of support beneath its foundations in an earthquake.

Dune Sand (Qd). Dune sand is a relatively clean, well-sorted sand placed by wind. These sands generally have a low potential for earthquake failure, but if the groundwater table is near the surface and the sand is loose, they have a high potential for liquefaction and consequent failure in an earthquake.

Quaternary Deposits, Undifferentiated (Qu). Graphic limitations required that some outcrop areas be combined and designated in Figure 1 as undifferentiated deposits. The most extensive formation included in undifferentiated deposits is the Colma Formation of unconsolidated sand and clay. Undifferentiated deposits also include alluvium, slope debris, some very small areas of bay mud, as well as dune sand, beach deposits, and fill. Most of the undifferentiated deposits have fair to good stability under earthquake conditions with small areas such as the bay muds and landslide areas having a relatively poor resistance to earthquake damage.

Franciscan Group Rocks, Undifferentiated (Kju). The undifferentiated Franciscan Group, consisting of serpentine, graywacke, chert, greenstone, shale, gabbro, diabase, and minor metamorphic rocks has good stability under earthquake conditions.

Intensely Sheared Franciscan Group Rocks (Kjs). The highly sheared Franciscan Group rocks are considered to have relatively low stability under earthquake conditions. Because intensely sheared rocks have undergone structural deformation and mineralogic changes, their properties may be completely different from those of the unsheared rock. Physical disintegration of rocks results in decrease in size, which sometimes produces very fine, sand-like, angular breccia. Mineralogic changes generally result in the formation in very fine aggregates of a mixture of soft platey minerals such as the mica-type mineral called sericite, and the clay mineral, montmorillonite. The mica-type and clay minerals have little strength and tend to shear very readily, particularly when saturated. Thus, the presence of these minerals increases the potential for landsliding or other failure.

FAULTS

General Statement

Movements on faults and earthquake activity are closely related in the western United States. Very slow continuous differential movement of land masses results in elastic deformation of the crustal rocks near a fault. This process may or may not be accompanied locally by slow differential movement of the ground surface (creep) along the trace of the fault. The fault often remains locked until the accumulated stresses are sufficient to cause sudden deep fracturing and movement on the fault, which may or may not be accompanied by surface rupture. The energy released during such a rupture causes earthquakes. Displacement resulting from ground surface rupture along the trace of the fault may range from 10 to 20 feet or more in large earthquakes. Small displacements of the ground surface, on the order of 1 foot or less, may also occur along subsidiary faults in the vicinity of the causative fault.

In the San Francisco earthquake of 1906, a maximum ground displacement of 20 feet was observed in Marin County, north of San Francisco. Ground rupture was also observed on the San Andreas fault where it passes along the peninsula south and southwest of San Francisco. Although ground rupturing was observed in San Francisco as a result of the 1906 earthquake, all of it was attributed to soil failure rather than surface rupture on faults.

Determining fault locations is important for the evaluation of earthquake hazards. Vibratory ground motion, the greatest cause of damage in earthquakes, originates at depth on the fault plane. The distance of the causative fault from the point of measurement is a major determinant of the intensity of observed ground motion. A second cause of damage in earthquakes is rupturing along the fault trace. Structures located on the trace of a fault which undergoes surface rupture during an earthquake would probably be destroyed. Therefore, identifying the locations of active faults that might move during an earthquake is of considerable importance. Inactive faults are those that have moved in past geologic time, but have not

moved in recent geologic time and are not expected to move during an earthquake.

Major Faults Near San Francisco

Major faults in the vicinity of San Francisco are known to be active and will be the source of future large earthquakes. The largest fault near San Francisco is the San Andreas, which ruptured during the 1906 earthquake. The San Andreas fault passes within about one mile of the southwest corner of the city and about five miles from the center of the city.

Another large active fault associated with major earthquakes is the Calaveras fault, which passes east of San Jose near Pleasanton, trending in a northwesterly direction. The Hayward fault trends in a northwesterly direction along the base of the hills in Berkeley, Oakland, and San Leandro. Although these faults have produced major earthquakes, they are not as large as the San Andreas fault and are not believed capable of producing earthquakes as large as those that have occurred and may occur on the San Andreas fault.

For the purposes of this study, it is conservative to postulate that the future large earthquake will occur on the San Andreas fault, which is both capable of producing the largest earthquake of those in the vicinity of San Francisco and is closest to San Francisco. If this earthquake should occur on the Hayward or Calaveras faults, the level of vibratory motion experienced in San Francisco would probably be less than if the earthquake were located on the San Andreas fault. However, the general effects would be similar and a similar distribution of damage in the city, particularly in the eastern part of the city, would occur.

Faulting Within the City of San Francisco

No active faults are known to exist within the city of San Francisco. The fault location map accompanying this report shows inactive faults, none of which are capable of producing as large an earthquake as has occurred on the San Andreas fault, and none of which are expected to move in a future major earthquake.

The presence of the faults shown in Figure 2 is known from the geologic mapping performed by Bonilla (1971) and Schlocker, et al. (1958). Fault locations were observed in bedrock outcrops, but cannot be discerned in recent deposits such as alluvium or dune sand, which blanket large parts of San Francisco.

Fault zones are normally susceptible to rapid erosion and therefore frequently occupy valleys, gullies, or sometimes lie along the base of a slope. In these locations they may be covered by alluvial materials or dune sand.

There are two wide fault zones, characterized by intense and pervasive shearing and containing sheared serpentine intrusives, which trend northwest through the city. These are termed melange zones, which means a zone of highly sheared heterogeneous rocks containing hard inclusions of diverse rock types.

One of the melange zones recently mapped by Bonilla is called the City College fault. Its northernmost extension is at the location of the Sunset Reservoir, but it probably continues northwesterly beneath the dune sands and finally passes into the ocean near Land's End. The second of these zones was observed by Lawson (1908) and later described by Schlocker. It extends southeasterly from a point on the shore about a mile south of Fort Point to Potrero Point near 22nd and 3rd streets. Although Schlocker did not show this as a fault zone on the geologic map, he described it as a zone of major shearing occupied by sill-like serpentine bodies.

Based upon new theories of plate tectonics, these are now believed to be zones of ancient thrusting called subduction zones. A subduction zone is an elongated region along which a crustal plate descends relative to another crustal plate. According to current theories, these zones in San Francisco date back to an ancient tectonic regime during which the crustal plate occupying the Pacific Ocean was being thrust beneath the crustal plate of the North American continent. Interaction between the continental plate and the Pacific Oceanic plate still continues but in the past 25 or 30 million years it has been typified not by underthrusting

of the Pacific Oceanic plate but instead by the northerly movement of the Pacific plate along the San Andreas fault.

The melange zones are of great geologic importance and much geologic and structural history can be read from them. However, they are inactive and have no significance with regard to current earth movements. They are important from the standpoint of engineering geology because the rock contains abundant platey minerals and represents a zone of potentially unstable ground.

There is no evidence to indicate that any faults in San Francisco, either those that are exposed and have been mapped or those thay may be concealed, are active. The seismic networks maintained by the University of California and by the United States Geological Survey (USGS) to determine the locations of microtremors clearly delineate active faults in the bay region, such as the Hayward fault, the Calaveras fault, the San Andreas fault, and few microtremors have been observed in San Francisco. Those that have been observed suggest that there may be some tectonic activity deep below the ground surface in the vicinity of San Bruno Mountain. If there is tectonic activity in this region, it could be related to strain along the San Bruno fault, which parallels the San Bruno Mountains and passes through Lake Merced. The absence of significant microearthquake activity within the city strongly supports the view that there are no active faults in San Francisco.

In summary, the results of geologic field mapping do not show any evidence of active faulting in San Francisco. Similarly, the results of microearthquake monitoring, which has delineated active faults in other parts of the San Francisco bay region, do not show evidence of active faulting within San Francisco. It can therefore be concluded that the faults in San Francisco are inactive and it is not necessary to restrict land use in their vicinity.

DISTRIBUTION OF SEISMIC INTENSITY IN SAN FRANCISCO

General Statement

Earthquake intensity is measured by the degree of shaking at a specified place based on evidence recorded by a trained observer. Earthquake effects used to typify different degrees of shaking vary from the slightest perceptible tremor to destruction of brick chimneys and entire buildings. The most violent shaking results in fissuring of the earth, tossing of boulders, and other unusual ground disturbances. The most commonly used intensity scale is the Modified Mercalli scale, although Japanese and Russian specialists have developed their own earthquake intensity scales.

There is general agreement that earthquakes in the western United States are caused by movement of the earth's crust along faults. A fault is a surface or zone along which the rocks have ruptured and displaced. Earthquake intensity is affected by the nature of the fault movement at the source of the earthquake, the location of the site with respect to the source and the causative fault, the travel path followed by seismic waves from the source to the point of measurement, and the geologic properties of materials at the point of measurement. Some of the factors at the source that affect resultant earthquake ground motion are the direction and amount of movement on the fault, the focal depth, e.g., the depth of the point at which rupture along the fault surface is initiated, and the physical properties of the rocks that are ruptured.

As seismic waves radiate outward from the point of origin, they are attenuated, with higher frequency vibration attenuated more than lower frequency vibrations. Seismic waves are transmitted upward from hard bedrock through softer soil layers that may consist of various types of alluvium or weathered materials. Because surface materials have distinctly different properties from bedrock materials, they affect the character of the seismic motions. Some researchers maintain that soft soils amplify weak ground motions but may attenuate strong ground motions in both high and low frequency ranges due to inelastic deformation of the soil (Ambraseys, 1973).

The effect of surface soil layers on ground motions is determined by physical properties of the soil layers, and their thickness. Surface motions may also be affected by nonuniform subsurface configurations (Trifunac, 1971). Alluvial sites may exhibit a resonance of ground shaking at certain frequencies that are determined by the physical properties of the soils and the depth of the soil layer (Seed and Schnabel, 1972).

While recent studies (Davis and West, 1973; Boore, 1972) indicate that topographic highs can cause ground motion amplification, the 1906 earthquake suggests that such amplification either did not occur in San Francisco or was compensated for by the comparatively lower levels of ground motion in the hard materials that compose the hills of San Francisco.

Parameters of ground shaking at the earth's surface are the duration of shaking, the frequency of the vibrations, and the peak acceleration or peak particle velocity of the ground movements, which are normally measured by strong motion instruments activated automatically at the onset of an earthquake. Instrumental records are important for quantifying these parameters and are essential in the study of earthquake ground motion.

One of the major objectives in earthquake engineering research has been to predict the characteristics of ground shaking at a given site for a future earthquake so that structures and facilities can be designed so as to minimize damage and loss of life in future earthquakes. Most recent theories developed for this purpose consider probability and magnitude of future earthquakes as well as attenuation and site effects. These considerations have for some time been applied to the construction of valuable and important structures.

Techniques for determining seismic characteristics of sites have been applied to larger areas, such as municipalities (Algermissen, 1973; Donovan, 1973; Seed and Schnabel, 1972). This is called microzonation in contrast to earlier seismic zoning that considered areas as large as

the United States. Site investigations are more detailed than microzonation of a city, but the generalizations inherent in a microzonation are needed when considering larger areas. The objective of microzonation is to compile maps showing different degrees of seismic hazards within the area of interest. These maps can be used to help determine safer construction design procedures, mitigate existing hazards, and as an aid in intelligent land-use planning.

Characteristics of Future Earthquakes

The future major earthquake would probably be located on the San Andreas fault, which is a strike-slip fault (one having a predominant lateral displacement), with the west side of the fault having moved northward. A future major earthquake accompanied or caused by movement on the San Andreas fault would probably have a fault mechanism similar to that of the 1906 earthquake. It is conservatively assumed that the Richter magnitude of this event would be 8.3, the same as the 1906 earthquake. The duration of strong shaking, which is strongly dependent on the length of faulting (Bolt, 1972), is also estimated to be the same as that for the 1906 earthquake, in this case 40 seconds.

This duration and estimated frequencies of predominant ground shaking for areas of the city having different soil types and depths have been used with the map showing estimated relative intensity of ground shaking (Figure 3) to characterize anticipated ground motions in various parts of San Francisco due to a future major earthquake located on the San Andreas fault near San Francisco.

Generally accepted theories regarding rupture of the earth's crust during earthquakes indicate that the actual breakage originates at a point and then radiates outward on the fault plane (Bolt, 1972). The epicenter of the 1906 earthquake is generally believed to have been located in Marin County about 20 miles north of San Francisco. Because earthquake epicenters are usually distributed along the causative fault, a future earthquake would be expected to occur at a different location on the fault than that of the 1906 event. In this event, the travel paths of seismic waves reaching the city and the levels of ground-shaking intensity in the city would also probably change.

Seismic Intensity Distribution Map

Determination of seismic intensity or degree of ground shaking, duration, and the frequency distribution of ground motions is the most important aspect of seismic safety evaluation, because these factors cause most of the catastrophic damage and loss of life in major earthquakes. Documentation of earthquake effects in San Francisco due to ground shaking in the 1906 earthquake (Wood, 1908) shows that distribution of ground shaking in the city was generally what would be predicted using current analytical techniques. The empirical evidence from this earthquake is therefore a valuable guide in predicting the intensity of ground shaking due to future major earthquakes, especially because many aspects of earthquake ground motion cannot be accurately predicted by present analytical methods.

Seismic waves during a future major earthquake may approach the city from a different direction than in the 1906 earthquake and will emanate from a source at the rupture front, which may be traveling in the opposite direction than in 1906. These factors might produce differences in frequency distribution of ground motions and in distribution of ground-motion intensity within the city. However, site characteristics change very little or not at all, and they have a major effect on seismic intensity and frequency distribution of ground motions. Therefore, it is believed that the distribution of ground-shaking intensity due to the postulated future earthquake will probably, without major differences, be approximately the same as that of the 1906 earthquake.

Based upon the work of Wood (1908) the Figure 3 map has been compiled to show estimated relative intensity of ground shaking in San Francisco for a future major earthquake similar to the 1906 event. Algermissen (1972) estimated that such an earthquake would have a return period of 170 years. Wallace (1970) estimated a recurrence interval of 102 years for a magnitude 8 earthquake on the total length of the San Andreas fault based upon crustal movement studies. He noted that this could be incorrect by at least a factor of 2 and that for a single point on the fault the interval should be 43 times greater. Tuncel and Kuo (1974) statistically predicted a maximum magnitude 8.5 earthquake with a return

period of 100 years for California and Nevada. Although neither of these estimates are directly applicable to the San Francisco seismic hazard, both appear to indicate a longer return period than Algermissen did for the San Francisco earthquake. The different zones shown in Figure 3 have been converted to equivalent estimated values of ground acceleration for use in building-damage predictions by comparison with building damage in other studies, where the level of ground acceleration was determined by instrumental measurement, and by judgment based on experience in building-damage studies.

Frequency distribution of earthquake ground motions can be estimated based upon soil properties and soil depth (Structural Engineers Association of Northern California, 1973). This has been done throughout the City of San Francisco, and the results have been incorporated in estimates of building damage.

Seed (1969) and others have pointed out that the extensive damage observed by Wood in the filled areas of San Francisco was due largely to soil failure beneath the fill rather than to intensity of shaking. First-class buildings in the filled areas whose foundations did not fail, such as those on pilings, suffered damage but were not in danger of collapse. The map prepared by Wood (not shown) is based almost entirely on building damage where buildings were present. Damage caused by vibration of buildings and damage caused by soil and foundation failures cannot always be differentiated, and Wood did not make this distinction. This has been taken into account in using Wood's data as an aid to compiling future damage predictions.

Figure 3 generally agrees with theory regarding ground motion amplification. The upper portions of the hills that consist of bedrock with little or no soil cover would undergo lesser degrees of seismic intensity. The lower portions of the City of San Francisco, which are built on man-made fill placed over soft bay muds, would undergo the highest degree of seismic intensity, and the zones lying between the man-made fill or deep-soil areas and the outcropping portions of the hills would undergo intermediate levels of seismic intensity.

LANDSLIDE AREAS

General Statement

A landslide is a downslope movement of a soil or rock mass due to gravity and is part of the natural processes by which uplifted lands are eroded. Landslides vary greatly in such characteristics as rate of movement and size. The slope of the surface on which landsliding may occur varies from quite steep to almost horizontal. The basic cause of landsliding is loss of shear strength in materials that are under stress due to the weight of overlying soil or rock.

Saturation by water is a frequent cause of landsliding because various contingent effects result in loss of strength in the soil. Landsliding of nearly horizontal ground toward an open or unconfined surface such as a stream bank or canal bank frequently takes place in strong earthquakes. Liquefaction of a sandy stratum beneath the ground surface often provides the slide plane along which such a mass may move. This phenomenon is called lurching. Other conditions which may contribute to landsliding are stratification planes, fractures, and shear planes or clay strata that dip downhill toward an unconfined surface.

Man's activities frequently are causes of landslides. These most commonly include undercutting near the base or toe of a slope or loading its crest. Changes in groundwater and surface-water patterns due to paving or construction also contribute to landslides by diverting water into ground which may formerly have been much drier and consequently more stable.

Earthquakes are rarely the sole cause of landsliding but large quakes frequently trigger sliding of potentially unstable ground. In San Francisco, it is anticipated that a major earthquake will cause movement of active slides and will trigger new slides similar to those which have already occurred under normal conditions and in the same general areas.

Landslides in San Francisco

The map showing landslide locations within the city (Figure 4) delineates the existing hazardous sites as determined from USGS maps and from records of the City of San Francisco Bureau of Building Inspection (Table 1). It is probable that a considerable number of slides have occurred that for various reasons have not been recorded in either of these compilations. However, such omissions do not substantially detract from the main purpose of this study, which is to identify general areas rather than specific sites that are subject to landslide hazard. These general landslide areas are shown in Figure 4.

According to Radbruch and Wentworth (1971), San Francisco has a relatively low abundance of landslides. These authors place most of San Francisco in Zone 1, which has the lowest relative landslide frequency. The hilly regions of the city are designated as Zone 2. Six zones of relative landside frequency in the Bay Area of which Zone 6 has the most landslides, are shown by the writers. Wright and Nilsen (1974) have also contributed to knowledge of landslide hazard in San Francisco.

The hills of San Francisco, underlain by Franciscan rocks, are the areas most susceptible to landsliding. The rocks outcropping in San Francisco northeast of the shear zone that extends from the vicinity of Fort Point to Potrero Point near 22nd and 3rd streets are predominately shale and sandstone. These rocks, although subject to sliding along stratification planes, are generally much less susceptible to failure than are the other rock types of the Franciscan group. Within the northeastern part of the city, the area that has been frequently subject to landsliding and rock falls is located along the eastern and northeastern margin of Telegraph Hill where, in many instances, the lower part of the hill has been excavated, creating steep and hazardous cliffs.

In the southwestern part of the city, the hills consist of or are underlain by diverse Franciscan Group rocks such as greenstone, schist,

chert, serpentine, and weakly metamorphosed basalt. Most of these rocks are susceptible to landslide failures.

A number of landslides have occurred in the San Miguel Hills or Diamond Heights area, particularly in the southern part of these hills near Mount Davidson. Landslides have also occurred to the east in the Bernal Heights area and around the small hill occupied by Bayview Park in the southeastern part of the city.

Landslides are abundant along the high sea cliffs extending between Fort Point and Seal Rocks. These landslides are a natural consequence of the slow but constant retreat of the shoreline as it is worn away by wave action..

A large part of the city is blanketed by deposits of dune sand, particularly in the western area. This type of sand, in low-lying areas where the water table is near the ground surface, may be subject to failure by liquefaction in earthquakes. During the San Francisco earthquake of 1957 there were several instances of landsliding caused by liquefaction around the margin of Lake Merced. Most of the dune sands in San Francisco are not situated at a low level near the water table. Where dune sands are located on higher ground they are relatively resistant to landsliding because of the natural high shearing strength of the sand and because shear strength of sand is not adversely affected by downward percolating groundwater.

TABLE 1

TABULATION OF SLIDE LOCATIONS

AND NUMBERS CORRESPONDING TO THOSE IN FIGURE 4

Slide	Location	Slide Number Shown in Figure 4
Seacliff Avenue	At China Beach	1
Parker Avenue	Bet. Turk and Anza	2
Grandview Avenue	Bet. Romain and Morgan	3
Market Street	Bet. Romain and Glendale	4
15th Street	At Carona Hts. Playground	5
Turk Street	Nr. Baker	6
Mangels Street	Bet. Genessee and Foerster	7
Laidley Street	Bet. Mateo and Roanoke	8
San Jose Boulevard	Bet. Randall and Highland	9
Joost Avenue No. 1	Bet. Arcadia and Baden	10
Kirkwood Avenue	Nr. Mendell Street	11
Monterey Boulevard	Bet. Detroit and Congo	12
Joost Avenue No. 2	Bet. Detroit and Congo	13
Alemany Blvd.	Nr. College Ave.	14
Silver Avenue	Bet. Congdon and Madison	15
Diamond Street	Bet. 27th and Army	16
Holladay Avenue	At Powhattan Ave.	17
O'Shaughnessy Blvd.	At Encline Court	18
O'Shaughnessy Blvd.	Nr. Lassen Alley	19
Brussels Street	Nr. Mansell St.	20
Bayshore Street	Nr. Costa St.	21
Market Street	Nr. Dixie Alley	22
Foerster Street	Nr. Teresita	23

Slide	Location	Slide Number Shown in Figure 4
Diamond Street	Nr. Moffitt	24
Youth Guidance Center	At Woodside and Idora	25
Castanada Street	Nr. Clarendon Ave.	26
Ingerson Avenue	Bet. Coronada And Griffith	27
Harkness Avenue	Nr. Bishop	28
Edgehill Way	Nr. Ulloa	29
El Camino Del Mar	Nr. Fort Miley	30
Union Street	At Calhoun	31
Twin Peaks Blvd.	So. of La Place Canyon	32
Twin Peaks Blvd.	Bet. Panorama and Portola	33
Bache Street	Nor. of Alemany Blvd., bet. Benton and Ellsworth	34
Foerster Street	Bet. Mangles and Melrose	35
Alder Street	Street 61 Bet. Harkness and Ankeny	36
Brussels Street	Bet. Ward and Harkness	37
Brussels Street	Bet. Ordway and Ward	38
Burlwood Drive	St. 61, Bet. Los Palmos and Belle Vista	39
Canyon Drive	At South Hill Blvd.	40
Charter Oak Avenue	At Helena St.	41
Christmas Tree Point	Radio Station on Twin Peaks	42
Corbett Avenue	St. 98 bet. Golden Lane and Hopkins	43
Del Vale Avenue	Nr. O'Shaughnessy	44
Dalewood Way	Mt. Davidson	45
Melrose Avenue	At Foerster St.	46
Winthrop Street	Bet. Lombard and Chestnut (at Lombard)	47
Foote Avenue	St. 331, bet. Cayuga and SP Rlrd.	48
Fulton Street	At 48th Avenue	49

Slide	Location	Slide Number Shown in Figure 4
Grandview Avenue	Bet. 24th and 25th Sts.	50
Greenwich Street	Bet. Montgomery and Sansome	51
Helena Street	East of Elmira St.	52
Ina Court	At Mclaren Park	53
Clarendon Avenue	Between Twin Peaks and Stanyan	54
Junipero Serra	At Brotherhood Way	55
Lobos Street	Street 38, bet. Plymouth and Caine	56
Lincoln Park	Nr. Land's End	57
Teddy Avenue	At Alpha	58
Majestic Avenue	Bet. Summit and Lakeview	59
Macondray Street	Bet. Leavenworth and Jones	60
Maywood Drive	St. 190 bet. Brentwood Lane	61
Myra Way	Bet. Molimo and Dalewood	62
Miguel Street	Nr. Beacon St.	63
Midtown Subdivision No. 6	West Side of Twin Peaks Blvd.	64
Molimo Drive	Street 490, bet. Myra St. and Croix	65
Montgomery Street	At Lombard	66
Mountain Spring Ave.	Bet. St. Germain and Glenbrood	67
Mullen Avenue	Bet. Alabama and Peralta	68
Modoc Avenue	At Cayuga St.	69
Oak Park Drive	Bet. Warren and Christopher	70
19th Street	Bet. Noe and Sanchez	71
O'Shaughnessy Blvd.	Nr. Arroyo Way	72
Prospect Avenue	At Coso	73
San Jacinto Way	Bet. Santa Paula and San Felipe	74
17th Street	Bet. Temple and Ord	75
Wawona Street	Opp. 30th Avenue	76
Calhoun Street	Bet. Green and Union	77

LIQUEFACTION

General Statement

Liquefaction, the transformation of a granular material from a solid state into a liquefied state as a consequence of increased stress transmitted through the fluid that fills the voids between particles of a soil mass, results in reduced shear strength of the material. The shear strength of a sand is a function of the intergranular pressure in the sand and the coefficient of friction of the granular materials composing the sand. A qualitative description of liquefaction of a sand follows.

(1) A loose saturated sand subjected to vibratory loading tends to consolidate and consequently decrease in volume.

(2) The soil matrix collapses and transfers some of its load to the water.

(3) This load transfer increases the porewater pressure which decreases the effective shear resistance of the soil.

(4) Under appropriate conditions, this leads to liquefaction.

An example of the visual result of this process is what is commonly known as quicksand. This effect may also be seen on beach sands, where by tapping sands near the waterline, the sand may become liquefied such that a heavy object sinks below the surface. In terms of geologic structures, liquefaction often causes landslides and building settlement under vibratory loading. In the case of landslides, a soil stratum with the proper characteristics may liquefy under vibratory earthquake loading. Once liquefied, this soil layer loses its shear strength and allows overlying strata to slump or slide at a low angle.

Often associated with earthquakes are the effects of liquefaction -- waterspouts, sand and water seething from holes in the ground, the submergence or tilting of structures, and the re-emergence of buried tanks. Well pipes whose foundations are situated in firm material underlying a liquefiable material have been observed rising out of the ground, due to consolidation of the underlying sequence of strata.

Conditions for Liquefaction

Four conditions classify a soil as potentially liquefiable:

(1) A low degree of cohesion (low clay content)

(2) A uniformity coefficient less than 10

(3) A low relative wet density

(4) The presence of water

In general, clay-free granular sediments with a uniform grain-size distribution are considered to have the greatest liquefaction potential. These sediments generally have a mean grain size between silt (0.04 mm) and gravel (2.0 mm). For a sediment to liquefy, it must lie under or within the water table.

The classifications of liquefaction potential are most easily based on density. Sediments that meet the above four conditions and have relative densities less than 65% have a high liquefaction potential. The same sediments with relative densities between 65% and 90% have marginal liquefaction potential. Sediments with relative densities greater than 90% have low liquefaction potential, even under strong vibratory motion (Youd, 1973). Other factors are involved in determining the liquefaction potential of soils, such as the amplitude of vibratory shear stress and the number of cycles of strong motion (Seed and Idriss, 1971), but these factors are generally used for a detailed examination of a particular soil, and are used in this study in only a general sense.

The Liquefaction Hazard in San Francisco

Liquefiable soils pose a substantial hazard to San Francisco. Earthquake engineering experts generally agree that a great percentage of the damage caused by the 1906 earthquake was due to the liquefaction and subsequent subsidence of man-made land rather than to vibratory motion (Seed, 1967). Although unconsolidated soils transmit seismic waves, they are believed to absorb a great deal of the vibratory energy from large earthquakes, particularly in the high frequency range of ground motion. Unconsolidated sediments have been observed

to vibrate primarily at periods greater than 1 second, indicating that higher frequency motion may have been suppressed by energy absorbtion in the soil.

The problem of liquefaction is compounded by the fact that, particularly in the case of hydraulic land fills, subsurface soils may liquefy even though the overlying materials have been firmly compacted. In a summary report on the aspects of fill in San Francisco Bay, Seed (1967) states, "No matter how good a fill may be, shear failure and lateral displacement of the foundation soils on which it rests will inevitably lead to instability problems." The potential for liquefaction of foundation soils compounds the problem of determining the areas of liquefaction hazard in San Francisco. In general, all areas where man-made fill rests upon soft bay mud or unconsolidated sand may be considered to possess a liquefaction hazard potential. Also, areas underlain by dune sand where the water table is relatively close to the ground surface have liquefaction hazard potential. An area of particular liquefaction hazard exists along the waterfront, where bulkheads and quay walls are used to retain fill that may liquefy under vibratory motion. A great deal of damage may occur on the waterfront due to this type of hazard (Wiegel, 1970).

Another area of high liquefaction hazard is located in the western portion of the city where dune sands and a high water table coincide. The USGS is analyzing reports of damage during the 1906 earthquake and correlating those reports with possible liquefaction in the City of San Francisco (Youd, 1974; Nichols, 1974). The study is considering two areas that probably experienced liquefaction during the 1906 earthquake: the first is along Ocean Avenue to the north of Lake Merced, and the second is between Noriega and Kirkham Streets in the vicinity of 48th Avenue. These areas are shown in Figure 5 as possessing a liquefaction potential. Other areas near the coastline and around Lake Merced are also shown as having a possible liquefaction hazard. The liquefaction hazard map should be updated when the results of the USGS study now being made are released. A map showing elevation of the groundwater table would be a useful aid in future evaluation of liquefaction potential, and it is recommended that such a map be compiled.

In addition to the areas of potential liquefaction shown in Figure 5, liquefaction may occur in other isolated locations in the city, particularly in the zones of dune sands and artificial fill shown in Figure 1, the geologic map of San Francisco. Under conditions of a high water table following a particularly heavy rainfall, low-lying areas and gullies may become saturated and thus acquire a potential liquefaction hazard where none exists under normal conditions. Isolated or ephemeral liquefaction hazard areas cannot be accurately located in Figure 5, and the alternative of including large parts of the city in the liquefaction hazard area is considered excessively conservative. The risk can be reduced by appropriate building code procedures.

LIQUEFACTION GROUND FAILURE AT LAKE MERCED IN 1957 EARTHQUAKE (PHOTO BY M. G. BONILLA).

TSUNAMIS AND SEICHES

General Statement

Tsunamis are transient sequences of long-period sea waves generated impulsively by earthquakes, coastal or submarine landslides, or volcanic phenomena. Seiches are periodic oscillations of closed or semi-closed bodies of water caused by earthquakes or landslides that disrupt the normal boundaries of lakes, bays, or small oceans. The most common tsunamis observed in the San Francisco Bay Area are due to major earthquakes located in coastal areas of the Pacific Ocean. Islands in the Pacific, such as the Hawaiian Islands and Japan, are most susceptible to tsunamis, although 19 tsunamis of varying sizes have been recorded in the last 100 years at the Presidio Tide Station located near the Golden Gate. The elevation of a tsunami is measured in terms of the vertical run-up, or wave heights, of water at a coastal recording station.

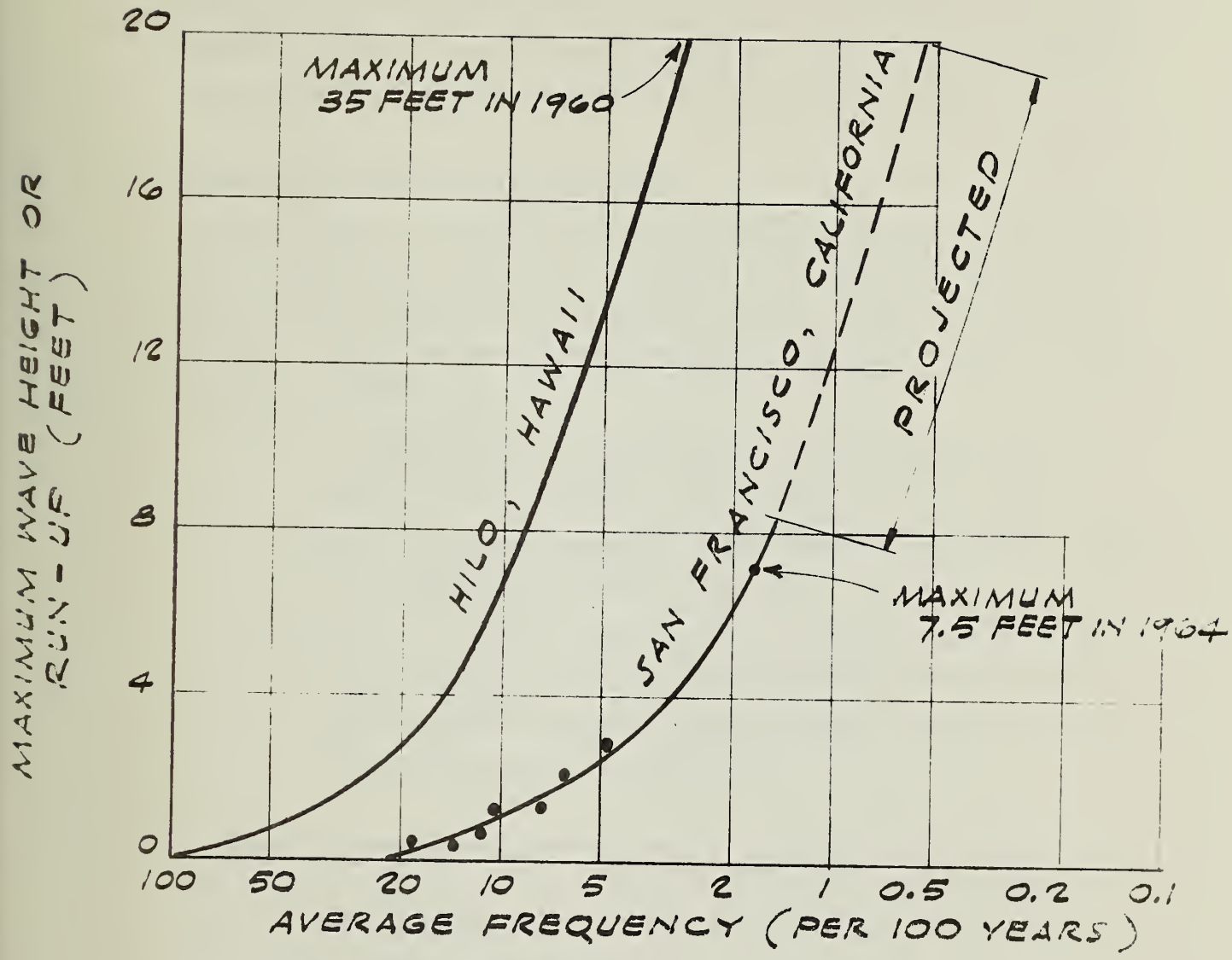
The physical dimensions and orientation of tsunamis and their travel paths affect the maximum expected run-up at different places around the Pacific Basin. Although data are sparse, run-ups such as those observed in Japan and Hawaii are not expected in the San Francisco Bay Area.

An understanding of the general properties of a tsunami will clarify what potential damage it may cause and how to plan a disaster-preparedness scheme. The velocity of propagation of a tsunami depends on the depth of water in which it travels. Typical velocities of propagation in the Pacific Ocean, where the average water depth is 14,000 feet, are 440 miles per hour. The distance between peaks of a tsunami is usually between 50 and 150 miles. The largest run-up of a tsunami generally occurs within the first 12 to 24 hours after the initial onset, but the effect may be observed for up to one week following this initial disturbance although the waves are greatly attenuated by the

second day. The period of these later waves is from 5 to 30 minutes, and the rate of change in water level for typical California records at Crescent City is as much as 1 foot per minute for periods of 10 minutes during the peak of the tsunami arrivals. When tsunamis impinge upon partly enclosed basins such as San Francisco Bay, the wave amplitudes are attenuated if the period of the basin is greater than the period of the tsunami. Conversely, tsunami wave amplitudes are amplified if the period of the bay is less than the period of the tsunami. Inside San Francisco Bay, tsunamis are generally attenuated and have had amplitudes similar to or less than the normal tidal range. This observation is supported by the theoretical calculation of the fundamental east-west period of oscillation of San Francisco Bay. Amplitudes of tsunamis are inversely related to water depth. For instance, an amplitude of 2.3 feet in 14,000 feet of water would produce a wave height of 10 feet in a 30-foot depth of water.

Historical Tsunami Data at the Golden Gate

Figure 6 shows the maximum run-ups in feet as recorded at the Presidio Tide Station and at Hilo, Hawaii. These run-ups are plotted as a function of average frequency per 100 years. The maximum at Hilo was 35 feet following the Chilean earthquake in 1960, and the maximum at San Francisco was 7.5 feet following the 1964 Alaskan earthquake. The curve for run-up greater than 7.5 feet at San Francisco is projected using the general relationship observed in Hilo, Hawaii. From this projection, a run-up of 13 feet may be expected once per 100 years and a run-up of 20 feet may be expected once every 200 years. The USGS has estimated that the probable maximum tsunami run-up at the Golden Gate will be 20 feet (Ritter and Dupre, 1972). The attenuation of the run-up in the bay will reduce the maximum run-up to 10 feet at Potrero Point near 22nd and 3rd streets and 2 feet near Alviso in the south bay. This maximum probable tsunami at the Golden Gate, although quite large with respect to the maximum observed tsunami here, seems nevertheless realistic. For example, the Hawaiian Islands had no large tsunamis during a period of almost 70 years, but during



TSUNAMI FREQUENCY OF OCCURRENCE AT SAN FRANCISCO GOLDEN GATE

FIGURE 6

the next 15 years four damaging tsunamis were recorded there. Consequently, this report recommends the use of a 20-foot run-up as the maximum probable tsunami at the Golden Gate. Such a tsunami could be disastrous to people and structures along the shoreline.

Effects of Tsunamis on San Francisco

Figure 7 shows the low-lying areas of the City and County of San Francisco that may be inundated by a tsunami with a 20-foot run-up at the Golden Gate. As part of a disaster-preparedness warning system, the following properties of a tsunami should be made public (after Ritter and Dupre, 1972):

(1) A tsunami is not a single wave but a transient series of waves. The first wave is not necessarily the largest.

(2) Swift current generated by receding and/or incipient tsunamis can damage moored boats and marinas.

(3) Before a tsunami or after the first wave, water may withdraw from the coast, exposing large areas of the shore. These exposed areas often attract people, who may then be trapped by the next incoming wave.

Although tsunamis would generally be hazardous only in the low-lying areas of San Francisco, the tsunami early-warning network that has been established in the Pacific Ocean should be part of the disaster-preparedness system in San Francisco.

Historical Seiche Data

A seiche in San Francisco Bay due to a local earthquake could cause substantial damage because the whole bay rather than just the area adjacent to the Presidio may be set in motion. In the Carnegie report on the 1906 earthquake (Lawson, 1908), the tide gauge at Fort Point near the Golden Gate showed a draw-down of approximately 4 inches shortly after the main shock of the earthquake sequence. Several subsequent draw-downs of 1 to 2 inches had a period of recurrence of 40 to 45 minutes, which agrees well with the east-west period of seiche oscilla-

tion of San Francisco Bay as calculated by the tidal division of the U.S. Coastal and Geodetic Survey for the Carnegie report. Because the 1906 earthquake, with its magnitude of approximately 8.3, did not excite a large seiche in San Francisco Bay, major earthquakes of the type that occurred in 1906 would not be expected to excite destructive seiches in the bay. Although an earthquake with a moderate vertical component, such as an earthquake on the Hayward fault system, might occur, earthquake records for San Francisco and the Bay Area do not indicate that a seiche from such an earthquake would exceed the maximum probable tsunami run-up.

The Effects of Seiches on San Francisco

The most likely generating mechanism for a seiche in the San Francisco Bay Area is motion along one of the major faults in the Bay Area, i.e., the San Andreas, Calaveras, or Hayward. Both seiches and tsunamis are generally created by movements of the earth that have a large vertical component. Although the major faults in the Bay Area are known primarily for their strike-slip, or horizontal motion parallel to the surface trace of the fault, vertical movements perpendicular to the trace of the fault may be possible, as shown by the considerable apparent vertical displacement on the Hayward fault at the base of the Berkeley Hills.

The maximum probable seiche in the San Francisco Bay would cause an estimated 10-foot run-up on either side of the bay. This estimate is based on very little information besides a reasonably conservative evaluation of the San Francisco Bay geometry and possible seiche-generating mechanism. The effects of a 10-foot seiche in the bay would be similar to those from a tsunami except the period of sloshing of this seiche from one side of the bay to the other may be greater than the period expected from a tsunami. Because the probable seiche-generating mechanism is due to movements along the greater axis of the bay, the most probable sloshing would be in an east-west direction.

Water contained in the city reservoirs will be affected by seiche, or sloshing, during an earthquake, and some water will probably be thrown out of the reservoirs. This may cause minor damage but is not considered to be a serious hazard except in the case of tanks located above the

ground surface. For these tanks there is a structural hazard due to seiche, which is discussed in Part II of this report.

STRONG MOTION INSTRUMENTATION

As part of the San Francisco Seismic Safety Investigation, the location of existing strong motion instruments must be defined and the need for additional instrumentation evaluated. A paper describes the need for seismic research on the effects of earthquakes on buildings and the necessity for strong motion instrumentation programs in cities with a seismic hazard: It is the Community Safety Element Background Paper No. 1, "Strong Motion Instrumentation," of the San Francisco Department of City Planning, which outlines the strong motion instrumentation program for the City of San Francisco. The paper contains a list of recommended future strong motion instrument sites and a map showing locations of existing instruments. The map and tabulations appear in Figure 8 and Tables 2 and 3, respectively.

Locations of the existing instruments were determined primarily due to fortuitous circumstances, without achieving an optimum variety of geologic and structural settings. Formal criteria for locations of new instrumentation are being developed at present. Preliminary drafts* of the proposed strong motion instrument locations show a good distribution of locations that take geologic conditions and structural improvements into account. This instrumentation program is vital for collecting earthquake data for strong motion earthquake analysis and seismic hazard abatement studies.

Strong motion instrument data are necessary for determining the seismic response of man-made structures to earthquake-induced seismac waves. Such recently gathered data have proved invaluable in estimating the seismic response of future earthquakes. In particular, seismic instrumentation is needed in buildings and in free-field locations near the hypocenter surface, or point of origin of the earthquake.

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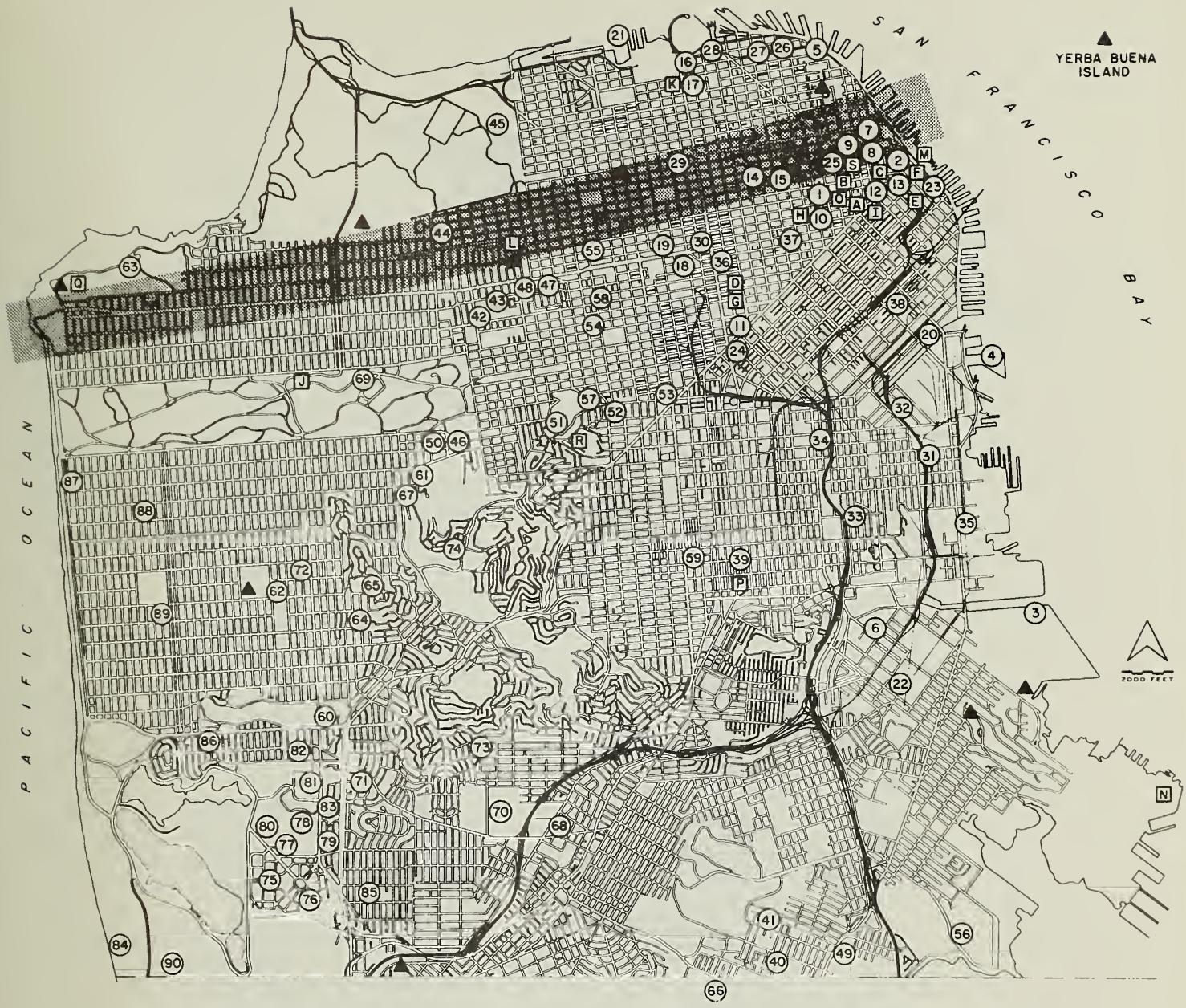
* These preliminary drafts have been prepared by the Seismic Engineering Branch of the USGS assisted by the Structural Engineers Association of Northern California (SEANC) and the Seismic Investigations and Hazards Survey Advisory Committee (SIHSAC) subcommittees.



[A] Existing Instrument Locations Maintained by USGS, June 30, 1973

(2) Proposed Locations (SEANC, Seismic Instrumentation Sub-Committee, 1971)

Proposed Array of Instruments (California Division of Mines and Geology, May 1973)

▲ Tentative Proposed Locations of Free-Field Instruments (Instrumentation Sub-Committee, Seismic Investigation and Hazard Survey Committee, November 1973)

STRONG-MOTION INSTRUMENTS IN SAN FRANCISCO FIGURE 8

TABLE 2

LOCATION OF EXISTING STRONG-MOTION INSTRUMENTS IN SAN FRANCISCO MAINTAINED BY USGS, JUNE 30, 1973

Name of Site/ Location/Date of Installation			Address/Station No.	Block/Lot No. 13
A.	Alexander Building*		155 Montgomery St.	288/1
	1. Basement	11/12/34	1065	
	2. 11th Floor	11/12/34	1066	
	3. 16th Floor	11/12/34	1067	
B.	Bank of America		555 California St.	259
	4. Basement	10/22/69	1068	
	5. Concourse	10/22/69	1069	
	6. 22nd Floor	10/22/69	1070	
	7. 52nd Floor	4/27/71	1108	
C.	Life Insurance Co. of Cal.		100 California St.	236/15
	8. Basement	9/15/60	1071	
	9. 12th Floor	9/15/60	1072	
D.	Federal Building		450 Golden Gate Ave.	764
	10. Sub-basement	3/29/65	1073	
E.	U.S. Government Building		390 Main Street	3746/1
	11. Ground Level	9/23/68	1074	
	(12. Ground Level	9/23/68	1075 - Inoperative)	
	(13. 7th Floor	11/26/68	1076 - Inoperative)	
F.	Southern Pacific†		1 Market Street	3713/2
	14. Basement	1933	1078	
	15. 14th Floor	1933	1079	
G.	State Building		350 McAllister St.	765
	16. Basement	1933	1080	
H.	Harsh Investment Corp.		450 Sutter Street	285/6
	17. Basement	8/19/71	1114	
I.	Shell Building**		100 Bush Street	268/4
	18. Sub-basement	1934	1115	
J.	Golden Gate Park††		Park Presidio Drive	1700
	19. Prayer Bk. Cross (Vault)	1934	1117	

*Instruments replaced on 2/27/72
†Instruments replaced on 6/2/69
**Instruments replaced on 8/16/71
††Instruments replaced on 10/4/71

Name of Site/ Location/Date of Installation		Address/Station No.	Block/Lot No. 13
K. Eastman Kodak Co.		3250 Van Ness Ave.	451/4
20. Basement	10/8/71	1118	
21. 4th Floor	10/8/71	1119	
L. Fireman's Fund		3333 California St.	1032/3
22. B 3	10/29/71	1127	
23. 5th Floor	10/29/71	1128	
M. BART: Ventilation Structure & Tube			
24. Lower Vent	1/28/70	1136	9900
25. Sec. 16	1/28/70	1137	
26. Sec. 19	1/28/70	1138	
27. Upper Vent	9/10/70	1139	
N. Hunters Point			
28. Islais Creek	8/25/70	1157	4502
O. Pacific Telephone & Telegraph		555 Pine St.	270-32
29. Basement	12/1/70	1168	
30. 10th Floor	12/1/70	1161	
31. Penthouse	12/1/70	1170	
32. 8th Floor (Rack)	2/3/72	1198	
33. 16th Floor (Slab)	2/3/72	1199	
34. 16th Floor (Rack)	2/3/72	1200	
P. Pacific Telephone & Telegraph		333 25th St.	6527
35. Basement	6/22/72	1220	
36. 9th Floor	6/22/72	1221	
Q. VA Hospital		Fort Miley	1313
37. Basement	6/28/72	1225	
R. Randall Jr. Museum		199 Museum Way	2615
38. Ground Level	7/6/72	1228	
S. Transamerica Building		600 Montgomery St.	207/26
39. 3rd Basement	3/1/73	1239	
40. 24th Floor	3/1/73	1240	
41. 49th Floor	3/1/73	1241	
42. 58th Floor	3/1/73	1242	

TABLE 3

PROPOSED STRONG-MOTION INSTRUMENT LOCATION:
SEISMIC INSTRUMENTATION SUB-COMMITTEE,
STRUCTURAL ENGINEERS ASSOCIATION,
NORTHERN CALIFORNIA, 1971

1. P.T.&T. Building
2. Bethlehem Building
3. LASH Warehouse
4. Port of San Francisco Warehouse
5. Sewage Disposal Plant
6. Bank of America Building, Toland & Jerrold
7. Golden Gateway Residential Tower
8. Alcoa Building
9. Appraisers Building
10. Sutter Stockton Garage
11. Fox Plaza Building
12. 111 Pine Building
13. P.G.&E. Building
14. The Comstock Apartments
15. The Nob Hill
16. Fontana
17. Galileo High School
18. St. Mary's Cathedral
19. The Sequoias
20. China Basin Building
21. Fort Mason Building on West Pier
22. S. F. Sewage Treatment Plant
23. Post Office Rincon Annex
24. Bank of America Service Center
25. Chinese Cultural Center
26. Otis Elevator Building
27. Longshoremen's Building
28. Cannery
29. Apartment Building, 1800 Pacific
30. NCR Building
31. W. J. Lancaster Building
32. Golden State Magazine Building
33. Colyear Motor Sales
34. United Parcel Building
35. American Can Building
36. Lincoln Mercury Building
37. Downtown Center Garage
38. 475 Brannan Building, Southern Pacific Railroad
39. P.T.&T. Building
40. Geneva Towers
41. Visitacion Valley Junior High School
42. University of San Francisco
43. Lone Mountain College
44. Temple Emanu-El
45. Letterman Hospital, Presidio
46. Polytechnic High School

47. Kaiser Hospital
48. Sears Roebuck Company
49. Schlage Lock Company
50. Parnassus Heights Medical Building
51. Apartment Building, 75 Buena Vista Ave.
52. Franklin Hospital
53. New Mint Building
54. Apartment Building, 1200 Fulton
55. Mt. Zion Hospital
56. Candlestick Park
57. St. Joseph's Hospital
58. California College of Podiatric Medicine
59. Immaculate Conception Academy
60. Scottish Rite Temple
61. U.C. Medical Center
62. Abraham Lincoln High School
63. Palace of the Legion of Honor
64. Herbert Hoover Jr. High School
65. Water Tanks
66. Cow Palace
67. Sunset Towers
68. Balboa High School
69. De Young Museum
70. City College of San Francisco
71. Medical Building
72. Lutheran Church
73. Safeway Store #759
74. St. John's Armenian Church
75. Park Merced Building on Piles
76. Park Merced Building on Spread Footings
77. Film, TV, & Radio Building, S. F. State College
78. Parking Garage, S. F. State College
79. Psychology Building, S. F. State College
80. Joseph Verducci Hall, S. F. State College
81. Stonestown Shopping Center
82. Joseph Magnin Store, Stonestown
83. Medical Building, Stonestown
84. Fort Funston or Police Target Range
85. Ortega School
86. Lucky Store
87. Pacifica Motel
88. Church of the Holy Name of Jesus Christ
89. St. Ignatius College Preparatory School
90. Olympic Club Country Club

RESERVOIR INUNDATION AREAS

General Statement

Man-made reservoirs which confine large volumes of water in tanks above the ground or behind dams and embankments represent a potential hazard due to possible earthquake failure. In case of failure, the released water would cause damage and might be a hazard to human life. The possible flood areas or inundation areas have been delineated as part of this study.

Earthquake damage to reservoir embankments can be divided into damage to the embankments themselves and damage to embankment foundations. Damage to an embankment would consist mainly of slope failure, longitudinal cracking and breaking, and settlement, while damage to a foundation would mainly include settlement and sliding. Such earthquake damage is closely related to ground conditions. Earthquake damage to cut slopes in natural ground would consist of surface fissuring and cracking of reservoir walls. However, cracking or fissuring of natural ground would probably occur on a small scale if at all. Earthquake damage resulting in failure of reservoirs excavated in natural ground is considered to be unlikely.

Based on these modes of failure and on engineering judgment, the following categories were developed to identify reservoirs with a potential earthquake hazard and consequently to determine areas of possible inundation.

(1) Reservoirs built above ground level
(2) Elevated water tanks
(3) Reservoirs and water tanks with storage capacity of one million gallons or more (those with a smaller capacity are not considered to be a significant hazard).

Table 4 shows characteristics of reservoirs and water tanks in these categories. (The Summit, Potrero Heights, College Hill, Hunters Point, and Twin Peaks Reservoirs are below ground surface, are not confined by dams

or embankments but by natural ground, and are therefore not considered subject to earthquake failure.) Areas of inundation due to earthquake damage to reservoirs and water tanks are illustrated in Figure 9. Note that some of the inundation areas were determined by the San Francisco City Water Department and are so indicated in Table 4. Areas of inundation as shown were based on the "Method 2 for Determination of Inundation Areas," developed by the Department of Water and Power of the City of Los Angeles. Figure 9 does not indicate flow depths within the potential inundation areas. Determination of flow depths would require information that is beyond the scope of this study, e.g., stability analyses of reservoir embankments, vibration analyses of elevated water tanks, and an extensive field investigation of the inundation areas.

TABLE 4

CHARACTERISTICS OF RESERVOIRS AND TANKS USED TO DETERMINE INUNDATION AREAS

Name	Location	Elevation (ft above msl)	Capacity (m.g.)	Full Depth of Water (ft)	Material	Cut or Fill
Lombard Street Reservoir	Greenwich & Hyde	303.0	2.7	17.5	Concrete lining & roof	Fill
Merced Manor Reservoir	22nd & Ocean	187.6	9.5	20.5	Concrete lining & roof	Fill
Stanford Heights Reservoir*	Agua Way & Teresite	614.0	11.0	20.2	Concrete lining & roof	Cut & Fill
Sunset Reservoir*	26th & Ortega	385.0	176.7	30.0	Concrete lining & roof	Cut & Fill
Sutro Reservoir*	Sutro Forest & Clarendon	499.5	31.4	22.4	Concrete lining & roof	Cut & Fill
University Mound Reservoir*	Bacon & University	172.0	140.9	26.4	Concrete lining & roof	Cut & Fill
McLaren Park Tank	McLaren Park & Mansell	451.0	8.0	--	Steel	--

* Areas of inundation determined by the San Francisco City Water Department

SUBSIDENCE

General Statement

Subsidence of the ground surface is a common phenomena, particularly long-term settlement which takes place over many years. However, strong ground motion, such as that from major earthquakes, may cause rapid and uneven local settlement of the ground surface. Such subsidence has occurred in San Francisco, most notably in the 1906 earthquake. Subsidence damages structures because of the uneven and rapid nature of the settlement. In San Francisco, the hazard area is largely restricted to areas of reclaimed land along the eastern waterfront where artificial fills are underlain by compressible bay muds and low-density sand.

Observed Subsidence in San Francisco

There are several reports of subsidence in San Francisco caused by the 1906 earthquake (Lawson, 1908). Many of these reports were given in terms of the visual surface damage and were not investigated thoroughly because evidence was destroyed by the fire following the earthquake. The area surrounding the Ferry Building, at the foot of Market Street, was emphasized in the Carnegie report. This is a district of "made" land (reclaimed by filling shallow water and marsh areas) in which a great deal of damage was caused. Although the Carnegie report implies that much of this damage was due to strong vibratory shaking, an analysis of the eyewitness accounts and the subsequent studies of surviving structures indicate that most of the damage in the made area of downtown San Francisco was due to subsidence and other forms of soil failures. The Carnegie report concludes by commenting: "This investigation has clearly demonstrated that the amount of damage produced by the earthquake of April 18 in different parts of the City and County of San Francisco depended chiefly upon the geological character of the ground. Where the surface was of solid rock, the shock produced little damage; whereas upon 'made' land, great violence was manifested. Other conditions, however, exerted a controlling influence." In support of this statement, examples are given in this report to emphasize that, despite the great

GROUND FAILURE ON THE EMBARCADERO NEAR THE FERRY BUILDING IN 1906 EARTHQUAKE.

intensity of motion observed near the waterfront, first-class modern buildings built upon deep piling or grillage foundations, such as the Ferry Building, were not significantly damaged. However, buildings constructed without adequate foundation preparation were seen to suffer extensive damage no matter how carefully the building itself was constructed. A classic example of survivability during a major earthquake in the filled land in downtown San Francisco is given by the cable-car system on lower Market Street. Because of a known tendency for differential settlement, caused by poor foundation materials throughout the whole area, the cable-car conduits were constructed upon piling to secure the grade. After the earthquake, the street sank on both sides of these conduits by as much as two feet, causing subsequent breaking and fissuring of the pavement but leaving the conduits intact.

Other examples of subsidence and major earthquakes around the world, such as in the 1960 Chilean earthquake, the 1964 Alaskan earthquake, and the Niigata (Japan) earthquake of 1964, have underlined the necessity for comprehensive subsurface analysis and preparation prior to the construction of major facilities.

Effects on Structures

Subsidence often results in what is called differential settlement of engineering structures. Facilities that span large distances, such as bridges and roads, and large structures that are underlain by soils of varying compaction characteristics are particularly susceptible to damage from subsidence. For instance, the abutments for a bridge are frequently supported on piling. Under strong shaking they will generally remain in place while adjacent backfill materials under the bridge approaches will subside. Sometimes buildings will settle at one corner or along one side, causing extensive cracking or tilting. Dams have also been known to subside unevenly, and the resulting differential settlement can cause serious cracking.

The Subsidence Hazard in San Francisco

Extensive damage from subsidence occurred in downtown San Francisco in the 1906 earthquake. The foundation materials in which the subsidence

occurred are still present and are capable of additional subsidence under strong earthquake motion.

Earthfill construction procedures and building foundation design techniques have improved greatly since 1906 so that modern major construction is probably reasonably safe. Buildings in areas subject to liquefaction or subsidence hazard are now usually designed so that they are highly resistant to such ground failure. For example, most large buildings built on soft soil are supported by pilings or by basements and foundations that extend beneath the soft soils. However, subsidence potential is a continuing hazard for many older buildings. In general, the areas shown on Figure 10 are those most susceptible to subsidence of the ground surface under strong ground motion. As delineated, the region comprises those low-lying filled areas in the eastern portion of the city in which the fill is either known to have subsided in the past or is expected to subside because of underlying compressible bay muds.

In addition to the outlined area of major potential subsidence hazard, there are no double small isolated local hazard areas throughout the rest of the city, such as artificial fill areas constructed with extremely compressible materials or small areas of very loose uncompacted dune sands. However, these are not expected to constitute a significant hazard except perhaps to one or two buildings in each area. On the other hand, the major hazard areas are known to incorporate small locations in which careful preparation of foundation materials had been undertaken or in which settlement has already occurred, thereby precluding any additional subsidence under earthquake loading. Neither of the above exceptions to the mapping of hazard areas created sufficient variation to justify any refinement of Figure 10.

GROUND FAILURE ON CAPP STREET BETWEEN 18th and 19th STREETS IN 1906 EARTHQUAKE.

IMPACT OF GEOLOGIC HAZARDS ON LAND-USE POLICY

General Statement

Comprehensive evaluation of geologic hazards can provide a basis for detailed land-use planning that will help minimize human fatalities and economic loss in future earthquakes. Land-use considerations must consider an acceptable level of risk versus cost of available aseismic procedures, and the relative degrees of hazard should be correlated with nongeologic considerations. The following general discussion of the impact of geologic considerations on land use is based on the earlier, more detailed descriptions of geologic hazards in this report.

The primary hazard to human life is not directly due to such earthquake effects as ground shaking or ground failure but to collapse of or damage to man-made structures. Therefore, population density and the structural analysis of buildings are the primary indicators of risk to human life.

The effect of most geologic hazards on buildings can be compensated for by engineering design procedures: regardless of their height, most structures can be appropriately designed for almost any site. However, the hazards of surface fault rupture and uncorrectable landsliding cannot be eliminated by design procedures, and land use of areas subject to such hazards must be unequivocally restricted. Because there are no known active faults in San Francisco, there are no hazard areas due to possible fault rupture, but there are many hazardous and precarious sites in San Francisco that might be subject to landsliding during a future major earthquake. Construction on sites with severe landslide hazard can be avoided by building code regulations. Such regulations would require sites situated in landslide-prone areas to be evaluated for landslide hazards by competent licensed professionals before a building permit is issued.

Building codes are an important means for implementing rational land-use procedures. Varying degrees of sophistication in preliminary

geologic and engineering evaluation can be incorporated into building code requirements to make them appropriate to types of proposed land use and to the varying degrees of geologic hazard present in different areas of the city.

Building code provision must consider both the geologic hazards and the proposed use of a specific site. Various uses might involve buildings of different construction type, different heights and occupancy rates, and special uses. The last category of buildings includes those that house public safety facilities, such as police and fire departments, those that house involuntary occupants such as hospital patients, school children, the aged, or prisoners, and important distribution facilities that house utilities or communications networks.

Professional earth science consultants make an important contribution to effective and workable control of land use, but in many cases the uncertainties involved in geologic hazard appraisal such as landslide evaluation expose consultants to extremely high liability risks. The cost of excessively high liability risks may be passed on to the builder and developer. Under such conditions consultants may elect to avoid certain types of geologic hazard evaluation or they might be compelled to resort to unrealistic and excessively conservative procedures. Therefore, measures intended to limit or distribute such liability should be supported by local government.

Ground-Shaking Hazard

Seismic hazard from ground shaking due to a future major earthquake is by far the most serious hazard to the City of San Francisco. Although ground shaking would affect all parts of the city, destruction caused by shaking would be concentrated among weak, poorly constructed, and poorly designed buildings.

Because engineering design and construction procedures that minimize possible structural damage due to ground shaking are available, restrictive zoning is not necessary or helpful for minimizing ground-

shaking damage. In other words, the degree of safety that can be achieved through careful engineering design procedures is probably equal to the degree of safety that could be achieved by restrictive zoning.

The different areas shown on the map of ground-shaking intensity (Figure 3) illustrate the relative hazards throughout San Francisco due to ground shaking. An adequate safety factor against ground-shaking hazard would be to incorporate requirements into the building code that ensure suitable aseismic design of structures. The geologic factors that should be considered are the various zones of ground-shaking intensity shown in Figure 3 and the type of building proposed for construction. Adequate aseismic design can be achieved for many structures by using building codes similar to those now in use. However, in the case of important structures with a large potential for loss of lives and economic loss, special soils engineering and geologic investigations, including subsurface exploration by drilling, should be required. An example of such a structure would be a high-rise office building located near the waterfront in an area of violent, or B, shaking intensity. An important part of these investigations would be evaluation of the predominant period of ground shaking as determined by soil depth and soil type and its relationship to the predominant period of the building.

An example of a situation involving intermediate ground-shaking hazard would be a building of approximately four stories high located in an area of strong, or D, intensity of ground shaking. In such a case, the requirements for geologic and soils engineering investigations could be less stringent. An example of low ground-shaking hazard would be a single story, wood-frame residence in an area of weak, or E, ground-shaking intensity. In this case, suitable aseismic design should result from provisions of a building code similiar to that in use today, and no special geologic or soils investigations would be necessary.

Landslide Hazard Impact

Landslide hazard areas, as shown in Figure 4, were derived primarily from study of known distribution of landslides and consideration of distribution of geologic formations and of topographic configuration. Recent work by Wright and Nilsen (1974) on landslide distribution in the southern San Francisco Bay region has also been considered.

A landslide appraisal by an earth-science consultant should be required for any proposed land use within the landslide hazard areas. Although there can be no assurance that all future landslides will occur within the hazard areas and that none will occur outside of these areas, observance of some precautions within the outlined areas constitutes a reasonable approach to minimizing this hazard. Exceptional sites lying outside the hazard areas, where local steeply inclined slopes or other conditions clearly indicate that the area would require landslide appraisal before development, should be required by an appropriate city agency to undergo landslide appraisal.

The thoroughness of landslide appraisal would vary depending on the characteristics of the site and the importance of the structure. This might be determined by the recommendations of the earth science consultant, subject to approval by the city.

Liquefaction Hazard Impact

An appraisal of liquefaction hazard by an earth science consultant should be required for any construction project within the areas of liquefaction hazard shown in Figure 5. The thoroughness of this appraisal should depend primarily on the importance of the structure because it is difficult to estimate relative susceptibility to liquefaction by surficial examination of a site. A similiar appraisal should be required for important or special use structures located in other areas of the city on materials other than bedrock.

Tsunami Hazard Impact

As shown on the map of possible tsunami inundation (Figure 7), the areas of San Francisco that might be affected by a tsunami are relatively

small. The size of the tsunami modeled on the map is equivalent to a 20-foot rise in water level at the Golden Gate, which is conservative. The probability of this type of tsunami occurring is much less than the probability of a major earthquake occurring.

Because the advancing ocean wave would be restricted upon reaching the Golden Gate, damage due to wave action is not considered likely to be a major factor. Damage due to inundation, however, would be severe, and planning for possible tsunami inundation should include the effect of inundation upon public safety facilities within the inundation areas.

The tsunami warning system, combined with an appropriate plan of action, should minimize possible loss of life due to tsunami inundation. Tsunami effects are not considered to pose a serious hazard to structural integrity of the larger buildings within the inundation area.

Impact of Inundation Due to Reservoir Failure

Areas of San Francisco that would be inundated as a result of failure of reservoirs are shown in Figure 9. This map does not imply that reservoir failure is anticipated during a future major earthquake. On the contrary, present construction procedures and review requirements relating to safety of dams and reservoirs are considered to provide an adequate factor of safety against reservoir failure during an earthquake. However, if due to some unforeseen circumstance a reservoir should show signs of possible weakening, the definition of inundation areas would make it possible to plan a warning system to alert persons whose safety might be threatened.

Subsidence Hazard Impact

Areas of San Francisco with a potential subsidence hazard are shown in Figure 10. The most severe subsidence hazard is along the eastern margin of the city where old, man-made fills rest on marshlands and bay mud. Aside from this region, subsidence due to vibratory densification of granular material, such as the dune sands that are prevalent in San Francisco, might occur if there are locations where heavy structures have been placed on sands of low to medium relative density.

It is recommended that an appraisal of subsidence hazard be required for most projects involving land use within the area of potential subsidence hazard shown in Figure 10. Some projects that might be excepted from this requirement would be ground-level parking lots, single-story, lightweight warehouse structures, or other lightweight buildings with low occupancy. High-rise structures or special buildings such as hospitals, schools, or public safety facilities might be required to provide appraisal of subsidence hazard in parts of San Francisco outside the area shown in Figure 10 if special conditions suggesting subsidence hazard appear to exist.

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PART II

STRUCTURAL EVALUATION

INTRODUCTION TO PART II

Part II presents results of a study conducted by URS/John A. Blume & Associates, Engineers, to identify and evaluate structural hazards during severe earthquake motion within the city and county of San Francisco. This work was conducted for the Department of City Planning of San Francisco under contract to the city of San Francisco. A parallel study, presented in Part I, was carried out on geologic and seismologic factors of earthquake hazards, and the work of the two studies was carefully integrated. Part II will include the problem of combinations of hazards -- geologic and structural.

The greatest hazard in San Francisco is that of buildings being damaged and destroyed from the shaking of the ground in a violent earthquake such as occurred on April 18, 1906. There are, however, other hazards such as those resulting from smaller but destructive earthquakes that have a greater probability of occurrence than the 1906 type. There is also the hazard of damage, failure, or loss of function of structures and systems other than buildings, including reservoirs, elevated freeways, bridges, utility systems, and storage tanks. In addition, there are secondary effects such as fire, panic, and disease, which have been experienced in the past after various earthquakes.

The main thrust of this study has been directed at estimating damage to existing buildings in present-day San Francisco that may result from a hypothetical repetition of the 8.3 magnitude 1906 earthquake originating on the San Andreas fault. However, lesser earthquakes and also other structures and systems are considered as well. The building study was intensive but limited to the use of building data provided by the City Assessor's Office. In other words this work is statistical insofar as specific building data are concerned. Except in a few trial cases, buildings were not inspected nor were their plans or details studied. No structural computations were made for specific buildings. A great deal of effort was expended in considering the types of buildings in the city, how these types have performed in other earthquakes, and how variations from the types that have been subjected to damaging earth-

quakes might be expected to perform in view of theory and empirical data. (The word "types" in this sense involves structural, architectural, and functional considerations as well as age and the design basis, if any, for earthquake motion.)

The basic presentation on estimated building damage is on one map, Figure A, which shows estimated building damage levels for a 1906-type earthquake. The report describes the basis for and the limitations of this map, and it is essential that the text be read for the proper use and interpretation of the damage estimates.

Also shown are two other maps for pre-code type C buildings in San Francisco, defined herein as masonry or concrete-walled buildings with wood floors and roof, built before 1948. Figure B shows residential pre-code type C living unit density on a block-by-block basis. Figure C shows pre-code type C nonresidential buildings on a block-by-block basis.

The estimates of damage levels were made carefully in the best state of the art manner and as well as possible under the scope of the contract and the availability of data. The estimates should not be considered predictions. With changes in San Francisco buildings, more data on earthquakes, and improvements in technology, the estimates should be revised sometime in the future.

ON EARTHQUAKE MOTION AND DAMAGE

Earthquake motion can cause damage of various types and degrees. The damage may be all structural in the sense that only man's structures are involved, it may be geologic where soils fail in various ways, or there may be combinations of structural and geologic failures.

Earthquake motion may be categorized into creep, permanent displacement, or vibration. Creep and permanent displacement generally have no effect on structures except those located directly over a moving fault. The San Andreas fault, which caused the earthquake of 1906, lies under the ocean opposite San Francisco. Because there are no active faults within the San Francisco city limits, only vibratory motion is of concern.

Vibratory motion would affect all of San Francisco. Every object and structure would be subject to seismic motion ranging to violent in severe earthquakes. The small 1957 Daly City earthquake had a Richter scale magnitude of 5.3 and caused about a million dollars of known damage. It was felt over all San Francisco. However, that motion was quite mild compared to that of local earthquakes having magnitudes of 6 to 8 or more, which are, of course, possible at any time. The vibratory motion of the ground will vary greatly in degree and in frequency content throughout San Francisco, which has soil conditions ranging from deep deposits of soft mud and fill to rock. Part I of this report discusses the various solid conditions and the shaking intensities of the 1906 earthquake.

As the ground moves back and forth it causes buildings to respond in a manner that is dependent in a complex way upon the building characteristics as well as the ground motion characteristics. Forces are induced by the tendency to resist motion, and these forces in turn cause stresses and strains throughout each building. If the stresses are great enough, damage starts to occur. If the strong motion continues, the outcome depends upon the structure's capacity to absorb further distortion without collapse. Some buildings have great ductility or toughness and can resist

continued strong motion after initial distress, while others may be strong but brittle and sustain very little additional motion after failure has begun.

History has shown that in general small wood-frame buildings with many partitions such as those in most San Francisco residential buildings have good earthquake resistance even though they move a great deal and sustain damage. They rarely collapse if well built. History has also shown that most pre-seismic code type C (now called type 3) buildings of unreinforced masonry or concrete bearing walls with wood floors and roof systems inadequately connected to the walls have poor resistance. There are many of these in San Francisco that were built prior to the first seismic codes of 1948. Buildings of all types constructed under modern seismic codes are expected to perform well, although it must be recognized that some damage is expected and that, because of variations and complexities, not all will perform well.

San Francisco Buildings in 1906

Although there was extensive damage to San Francisco buildings from the 1906 earthquake of 8.3 magnitude, photographs taken before the ensuing fire spread show that many structures were not damaged severely. Those buildings that collapsed were not what are here termed major structures, those of many stories, or of large area.

A document and photograph study of the major San Francisco buildings subjected to the 1906 earthquake indicated that most of them were put back into service in spite of both the earthquake and the fire. Many are in service today, including the Claus Spreckels building, the Ferry building, the Flood building, the Emporium, the Post Office at 7th & Mission Streets, the Fairmont Hotel, older portions of the St. Francis Hotel, the old Mint, the Rialto building, the older portion of the Mills building, the Monadnock building, and others. Notable exceptions were the old City Hall, the Majestic Theatre, and the original Palace Hotel which was a very strong class C building. The Palace Hotel withstood the earthquake quite well only to be burned out in the days following. Of 44 completed major pre-1906 earthquake San Francisco buildings, 38 were put back into use after repairs. In addition, there

NEW MONTGOMERY STREET AND MISSION STREET - CROSSLEY BUILDING - SAN FRANCISCO, CALIFORNIA, 1906.

were 7 major buildings under construction in April 1906, all of which were finally completed and put into service.

The records show that today there are over 25,000 San Francisco buildings still in service that survived the 1906 earthquake and fire. The number would be much greater if the fire had not occurred.

Further information of interest is that, of a population of about 400,000 the estimated dead from all causes was only 700 to 800. Of course, if the earthquake had occurred at a busy time of day rather than early in the morning the number of deaths would have been substantially greater.

In estimating damage to San Francisco from future great earthquakes, many factors must be considered besides those pertinent to the 1906 earthquake. Not only is the population greater now but there are many more buildings, and many are in different parts of the city than in 1906. The structures are of different types, and all current types are not necessarily more earthquake-resistant. There are higher buildings today and there is much greater concentration, especially in the financial and downtown shopping areas. One must also consider what has happened, and has not happened, in all the other earthquakes in the United States and elsewhere since 1906. Insofar as possible, theory must also be introduced but only with the exercise of sound professional judgment based upon current empirical and scientific knowledge. Experience in 1906, and elsewhere, must be carefully weighed and adjusted as necessary for current conditions in San Francisco.

Regardless of all these and other considerations, the fact remains that we do have at least general knowledge of how many buildings performed in 1906 under an earthquake similar* to the one with which we are now concerned. None of these buildings was designed under a seismic code. In fact, San Francisco's first official seismic code did not come into effect until 1948.

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*No two earthquakes are quite the same. There are so many random variables involved in factors that affect building performance that variations in performance are to be expected.

However, many of the major 1906 buildings were designed for wind forces, in some cases of a substantial amount, greater than used here today. Many of the tall buildings had substantial riveted steel frames designed by engineers of good judgment. Perhaps the outstanding feature of the old San Francisco buildings was that most had heavy filler walls of masonry and partitions of tile or masonry that were not considered as part of the structural system. Although these nonstructural elements added much weight, they also imparted strength well beyond that required to resist the wind.

A detailed study (Blume, 1960) has shown that there is a great difference in the structural dynamic characteristics of traditional buildings and those of contemporary buildings. Although the contemporary buildings have the advantages of seismic design, lighter materials, and better control of both design and construction, they generally lack the sometimes great advantages of the nonstructural or noncalculated materials and elements. Thus it cannot be said that contemporary buildings are all stronger or more earthquake-resistant than the 1906 buildings. Some are weaker and more flexible although in general their elements are interconnected better and are lighter weight.

An Example Building

Detailed analyses and many observations have been made of a San Francisco 15-story building that, although constructed two decades after 1906, has in general the characteristics of the 1906 skyscrapers, of which the tallest was only 19 stories. The building is narrow, it has a riveted steel frame designed for wind forces but surrounded with unreinforced brick masonry. It has concrete floors, stairways, and fireproofing, and it has many hollow tile partitions. It can be used as a valuable link between 1906 performance and current estimates of future performance. Any method of damage estimation should indicate results for this building similar to what happened to the tall buildings in 1906. This, of course, assumes a similar earthquake -- a necessary but not quite valid assumption. This example building has been extensively treated in the technical literature (Blume and Hesselmeyer, 1934; Blume, 1956, 1960; Hudson, 1960; Jacobsen and Ayre, 1938).

The building was designed for 20 pounds per square foot (psf) wind force, all taken in the exterior steel framing. This design would have less value than current seismic provisions would require. Although the predicted ground motion for a 1906 type earthquake would produce lateral forces of many times even the code value, there are three reasons why this building's predecessors survived in 1906: (1) the great strength and rigidity of the noncalculated elements, (2) the cracking, breaking, and grinding of these elements and the energy thus absorbed, and (3) the toughness of the steel frames in holding the elements essentially in place and resisting in their inelastic range beyond the yield point.

It is estimated for the example building that the lateral force needed to start to crack the brick filler walls would be about the code force. This could be greatly exceeded and the walls would be expected to crack and the pieces grind together. There would be damage, perhaps a great deal, but the building's dynamic characteristics would change so much from the damage that, with the residual steel frame well designed for wind forces, and with the great energy absorption of all materials, collapse would be unlikely. This, in effect, is a model of what happened in 1906 even though none of the buildings would be considered adequate by conventional contemporary standards.

In contrast, contemporary buildings have somewhat greater design coefficients and meet other code requirements that are highly desirable, but they generally lack the reserve value of the noncalculated walls and partitions. Instead of heavy masonry they have much glass and light weight covering with insulation. If the buildings are ductile or very strong they should survive, but there could be considerable damage in some cases.

It is desirable to have a method of damage estimation that somehow includes all these important factors. This is not directly possible with today's state of knowledge, but implicitly and empirically the damage estimation procedure does consider these factors. Although

this discussion has centered about tall or high-rise buildings, the same types of considerations must be employed for all classes of buildings.

Recent Earthquakes

Recent earthquakes including San Fernando 1971 (magnitude 6.4) show clearly that earthquake shaking can be stronger than at one time believed. Peak recorded accelerations in the last decade or so have been two or three times greater than prior measurements. On the other hand, buildings have been found to be much more resistant than given credit for in conventional design practice. There are exceptions, however, and they cause most of the trouble. A comparison to results in foreign earthquakes such as those in Caracas, Mexico City, Iran, Morocco, Turkey, Colombia, etc., shows that in general California buildings are stronger and more resistant than in most other places but California is also subject to the greatest earthquakes. The nominal loss of life thus far in California earthquake history has mainly been due to good fortune about the time of occurrence relative to population deployment and building usage.

SAN FRANCISCO BUILDING CODES AND BUILDING TYPES

San Francisco has had seismic design code provisions since 1948. However, the Riley Act, adopted by California in 1933, requires for all buildings (except those not primarily for human occupancy and up to 2-unit dwellings not in a city) a design lateral force of 2% of the dead and live load, or 20 psf wind force, whichever governs. In many cases the wind governed the design so that the buildings were not much different than pre-Riley Act structures. The Riley Act did focus attention on the earthquake problem, however, and this was beneficial.

Prior to 1906 there apparently were no specific lateral force design requirements. The designers of San Francisco's tall buildings generally followed eastern practice and no doubt provided rather substantially in some cases for wind forces. After 1906 there was a requirement for as much as 30 psf wind force for tall or slender buildings. This was changed to 20 psf in 1910, no doubt under the pressure of economics, and in 1920 it was further reduced to 15 psf.

The first San Francisco earthquake code was finally adopted in 1948 after years of effort and much resistance. It provided for lateral forces of from 3.7% to 8% of dead and live load for most buildings and the lateral force coefficient, C, was 10% for theaters. C varied with the number of stories:

$$C = \frac{2}{24+N} \quad \text{(if on good soil)}$$

where N is the number of stories.

C was increased 25% if the soil was marshy, and if the building was on rock C was reduced 15% from the above equation value. These requirements generally exceeded the wind design values, thus creating stronger buildings than before 1948.

Seismic code changes were made in 1956 and again in 1962, 1965, and 1969. The current code is similar to the Uniform Building Code, which in turn

follows the recommendations of the Structural Engineers Association of California. However, in some respects, the current San Francisco requirements exceed those in the Uniform Building Code.

From 1906 through 1947 the local codes set forth construction types for buildings categorized as types A, B, C, and F. These types were based on the materials of construction and the fire ratings, and in most cases there were limitations on height and floor area. A fireproof steel-frame building with the wall loads carried on the steel frame had no height limitations in San Francisco.

From 1948 on the designations changed to 1A, 1B, 2, 3, 4, and 5, with variations in the fireproofing, materials, heights, and floor areas. Currently there are no limitations on height for type 1A, structural steel-frame, fire-resistive construction, and type 1B, reinforced concrete-frame, fire-resistive construction.

The information on building types used in this investigation was limited to the Assessor's records which show only types A, B, C, S, and F, regardless of the year of construction. Because of the various code changes over the years it was not possible to reconcile completely all building types with the current records. For the purposes of this investigation, however, the following types were used in making damage estimates.

Type	Brief Description
A	Steel or reinforced concrete; fire-resistive; no height limitation*
B	Steel or reinforced concrete; less fire-resistive; height limitation*
C	Masonry or concrete walls, wood floors and roof
S	Light steel, incombustible (service stations)
F	Wood frame, limited area and height

*Depends upon and varies with the particular year and code

San Francisco has some excellent code requirements for class F buildings which, when small residential units, are good seismic risks. However,

there is a typical San Francisco type F building that could be a poor risk in its transverse direction if not properly braced. This is the two- or three-story flat on a narrow lot, often only 25 feet wide. The building usually has a double-width garage door, an adjoining stairway, and an open basement for parking and storage, leaving little space or provision for lateral bracing in the transverse direction. These buildings should be specially braced with walls, partitions, or knee braces. It was not feasible in this investigation to isolate the poor from the good class F residential buildings. All class F residential buildings have therefore been assigned good ratings.

Other reports have been made of certain estimated damage from a repetition of the 1906 San Francisco earthquake (ESSA/HUD, 1969; NOAA/OEP, 1972), and data from these (for San Francisco only) are summarized in Appendix D. However, the study reported here is the first to consider damage to all buildings and the first to provide damage level estimates on a block-by-block-basis.

Figure A is a map of San Francisco with four levels of damage indicated on a block-average basis for a 1906 type earthquake occurring in December 1973, the time when tapes with building statistics were made by the City Assessor's Office for this study. The ratings would apply also to the future, providing allowances are made for razed buildings, improved buildings, and new buildings subsequent to that time. The damage levels are described as follows:

Damage Level	Damage Description
Severe	Extensive to complete damage of nonstructural elements, and structural damage ranging from heavy to essentially total in some cases. Some collapses and many buildings for which replacement would be more economical or desirable than repair. There would also be damage as described for the lesser categories.
Heavy	Heavy damage to architectural and other nonstructural elements and materials. Structural damage extensive. Some structures out of plumb. There would also be damage as described for the lesser categories.
Moderate	Damage to many nonstructural elements and materials, partitions, walls, stairways, chimneys, etc. Some structural damage but not in all cases. There would also be damage as described for the slight category.

Slight	Some cracked and damaged walls, partitions, stairways. Broken chimneys. Parapets and ornamentations dislodged. Structural damage generally minor, if any.

Certain blocks and areas as indicated on the map were not covered in the investigation because there was insufficient data to estimate building damage, some structure other than a building occupies the area, or the area was not in the scope of the study.

In no case should damage intensity data be applied to individual buildings, for which damage can be estimated only by specific analysis. No specific analysis of any building has been conducted in or for this investigation. The building data used are those obtained from the Assessor's records and the estimation of damage has been by approximate, statistically based methods. Data on large areas or for average or statistical uses are expected to be meaningful for overall planning and related purposes.

The following should also be kept in mind when using Figure A. Ground motion and building resistance to ground motion are highly random variables, often with extensive variations from average or mean conditions. The data in Figure A are for mean conditions, and variation or exceptions in either direction can be expected in any local area.

Problems were encountered in the development of the building damage map because government buildings -- city, state, and federal -- did not have adequate data in the official records to estimate damage. These buildings may or may not occupy a whole block. Where they do, the buildings were rated as well as possible from available information, personal knowledge, or judgment. In no case was specific analysis conducted under this study. If a government building occupied only part of a block, the computer operation ignored the building with inadequate data and rated the block according to the nongovernment buildings. This could result in a few local anomalies.

Other anomalies would result from any errors in the records as to building types or ages or from the fact that the buildings had to be averaged for each block on the basis of the number of stories rather than building areas. In the latter case, a building of many stories in a block with other low buildings could have a strong influence on the block rating. A similar problem would exist for a building of unusually small or large floor area as compared to other buildings in a block, in which case the building would have too much or insufficient influence, respectively, on the block rating.

Figure A indicates structural damage only, without any allowance (except as may be indirectly reflected in the Wood rating of 1906 shaking intensity) for geologic hazards such as landslides, liquefaction, tsunamis, etc. Appendix A provides information on how the Wood ratings were used. Combinations of hazards will be considered later in this report.

Damage Estimation Procedure

There are many ways of estimating building damage from earthquake motion, but all must depend in good measure on empirical data and records of actual damage. To depend upon analysis and theory alone would generally result in over-estimation of damage because most, but not all, buildings have been found to be more resistant than conventional methods of analysis would imply. Few San Francisco buildings of 1906 would comply with current seismic building codes, and yet many of these buildings survived the earthquake and the fire that followed. There are over 25,000 pre-1906 buildings still in use today to demonstrate this point, and there would be many more if it had not been for the fire. This does not mean that the seismic codes of today are too severe because (a) many buildings did fail and many more were severely damaged, and (b) contemporary buildings do not have the generous amount of nonstructural materials and elements that are in older buildings (Blume, 1960).

The method of rating the buildings and finally the blocks for the map was determined only after extensive consideration of earthquake damage history and a reconciliation of that history with theory and design practice to the extent feasible. Consideration was given to peak

ground acceleration, spectral response acceleration, natural periods of deep or soft soil deposits, the seismic code if any under which each building was designed, the fundamental period of the building, the type, year, and materials of its construction, the number of stories, and the use category. Damage factor determinations were based upon the best application of the data available on the San Francisco Assessor's tapes in view of earthquake damage history, theory, and professional judgment based upon damage history and theory.

Considerable weight was given to building performance in San Francisco in 1906, and to building performance in the 1971 San Fernando earthquake, for which many strong motion records were obtained and for which there is considerable information on building response and damage. Other earthquake information and well-documented material from the response to ground motion from underground nuclear explosions were also considered.

It was recognized in damage estimation that both structural and dynamic building characteristics change as a building responds to strong ground motion and enters the important range between the start of distress and the point of complete failure. In many if not most buildings this is the area of greatest earthquake resistance and one that is not covered by conventional analysis or design procedures.

Building data were obtained from the Assessor's records on a block-by-block basis. The data were limited to the lot number in each block, the use category, the year built, the construction type, the number of stories, and the total floor area. Equations were developed to combine this information with the estimated spectral acceleration and to generate three damage factors for each building.

The damage cost factor is defined here as the ratio of damage repair cost to the replacement cost of the building. The replacement cost may be considerably different than the original cost of the building, or its assessed value times some constant, because of changes in values and construction costs. The damage cost factor as thus defined repre-

sents the relative amount of damage, with a factor of zero being no damage and a factor of one representing total loss of the elements under consideration.

The first damage cost factor represents the results with the assigned original, elastic period of the building and is damage of a type that would not materially impair the strength of the building even if the ratio were unity.

The second damage cost factor is based upon the response of the building assumed to have the rigidity and strength of only its structural elements. The assigned period is lengthened and thus the spectral acceleration may vary from that in the first stage of response. Resistance in the second stage depends not only upon the structural strength but the ductility and the capacity of the building to do work in the inelastic state between the onset of damage and failure.

The third damage cost factor, which was used to assess degrees of damage for plotting purposes, is based upon a weighted combination of the first two damage factors.

The small, wood-frame residential buildings -- type F, as described previously -- were not analyzed dynamically because of their excellent record and the amount of damage information on them. They were simply rated for damage proportionally to the short period or peak spectral acceleration which in turn depends upon the Wood rating. The typical San Francisco two- and three-story flats were not penalized for their possible weakness in the transverse direction on the assumption that adequate bracing has been or will be provided. Type S buildings (also described previously) of which there are few, were also rated similarly. All other buildings were analyzed as shown in Appendix A.

Specific details of analysis are not released so that the anonymity of specific buildings will be preserved. The analysis as well as the use of the results involves professional judgment.

For each block, average damage factors were obtained based upon the results for all buildings in the block. These average factors were weighted according to the number of stories in the various buildings. It would have been preferable to weight factors according to total building areas but this was found to be impossible because building area data were frequently missing from the records. Data on individual buildings are considered confidential and are not reported here or available. Block values represent the weighted average only and the values of the buildings in the block may vary considerably from the average. This would be especially true, for example, where a new building has been constructed in a block with many old, pre-code buildings.

Additional information on the damage estimation procedure is provided in Appendix A.

Earthquakes Other Than the 1906 Type

Figure A is for a 1906 type, 8.3 magnitude earthquake. There are, of course, an infinite number of other earthquakes with reference to magnitude, fault, and distance from the epicentral region. Hopefully, there will be none larger than the 1906 type, although earthquakes have occurred up to 8.9 magnitude elsewhere in the world. Most experts consider the 8.3 a reasonable maximum for the San Francisco area.

The smaller earthquakes, which are more probable in a given time period, could be estimated from the 1906 type data by considering the relative values of estimated spectral acceleration and assuming that the spectral response distribution throughout the city would be unchanged. In looking at Figure A, one could imagine smaller earthquakes which would cause the damage ratings to decrease, as, for example, "severe" ratings would become "heavy," "heavy" would become "moderate," etc. An extreme case almost at the damage threshold, would be the 1957 Daly City earthquake of 5.3 magnitude, for which the only ratings would be "slight" or "none." "None" was not used for the 1906 type because virtually every building would be expected to have some damage visible to a trained observer.

PRE-CODE TYPE C BUILDINGS

For the purposes of this report, pre-code type C buildings are defined as those buildings constructed before 1948 that have masonry or concrete exterior bearing walls with wood floor and wood roof construction. Such buildings are of particular interest because they have had a generally poor record in essentially all earthquakes where such structures existed. Although there have been notable exceptions, and there will be again in future earthquakes, type C buildings with unreinforced masonry walls and poorly connected floors and roofs have been severely damaged and some have collapsed. This type of construction is not to be confused with contemporary type 3 buildings designed and constructed under modern seismic code provisions. Furthermore, some pre-code type C buildings may perform well under earthquake motion because of unusually good construction, heavy walls with few and small openings, or other fortuitous conditions including favorable soil and foundations.

Information has been drawn from the Assessor's records to focus on pre-code type C buildings on a block-by-block basis and also according to the 1970 census tracts. This information is expected to be useful in locating problem areas for further investigation and for planning purposes. The buildings considered were those existing in December 1973.

Figure B shows the density of living units in pre-code type C buildings. The number of living units was obtained from the City Assessor's records for apartments, dwellings, flats, duplexes, flats and stores, condominiums, and hotels other than first class. The greatest density of such living units occurs in the downtown residential area of the city, generally but not exclusively bounded by Larkin, Bush, Mason, and Turk Streets. The damage levels shown in Figure A are strong in this general area.

Figure C shows the density of nonresidential pre-code type C buildings. This figure includes all building use categories except

apartments, dwellings, flats, duplexes, flats and stores, condominiums, and hotels other than first class. The greatest density of nonresidential pre-code type C buildings occurs in the South-of-Market area, but there is also an appreciable concentration of such buildings in the area bounded by Broadway, Sansome, Sacramento, and Stockton Streets. The damage levels shown in Figure A are also strong in this area.

Appendix B is a list of all pre-code type C buildings according to 1970 census tract numbers for the entire city. For each census tract and for this particular class of building, the list includes the number of living (residential) units, the number of residential buildings, and the number of nonresidential buildings.

Figures B and C can be used together with Figure A, and Appendix B can be used together with population densities, to assess the hazard from earthquakes in and about this type of building. The use of this material in hazard reduction will be discussed in a later section of this report.

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EARTHQUAKE DAMAGE TO TYPE C
MASONRY STRUCTURES IN SEATTLE, 1965.

STRUCTURES OTHER THAN BUILDINGS

Elevated freeway structures suffered severe damage in the 1971 San Fernando earthquake. Although many of these were high and slender compared to those in San Francisco, it would be wise to expect some damage, possibly in the heavy and severe categories, to San Francisco elevated freeways, especially in view of the fact that San Francisco has some very poor soil conditions as compared to the San Fernando area. Most of these structures have not been designed to resist severe dynamic distortions although some have been altered since the 1971 experience and some of the new structures have been designed to improved earthquake criteria.

The Bay Bridge and the Golden Gate Bridge will probably perform satisfactorily because they are long period, ductile structures. Other bridges in San Francisco are being studied by the Bureau of Engineering, Department of Public Works, and will not be reported herein except to note that the poor soil conditions associated with some of them could cause damage.

Reservoirs have been considered in the geologic report. Gasholders and storage tanks, surface and elevated, are special problems. Such structures have been damaged in earthquakes but many are quite resistant and some have specially designed resistance.

Waterfront structures, especially where situated on or alongside made ground, are subject to damage but this is generally not of a catastrophic nature.

Underground construction should generally perform better than surface structures although in very poor soil areas there could be problems, especially where there are abrupt changes in the structural section.

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COMBINATIONS OF GEOLOGIC AND STRUCTURAL HAZARDS

Figure A is based on the assumption that all buildings are located on stable soil and foundations. The geologic report contains maps for geologic hazards which should be treated as additional hazards. A building with a "slight" damage rating that is apt to slide down a hill with a landslide should have its rating changed to "severe," or perhaps to "total." Liquefaction could also increase damage, as could subsidence. Inundation from tsunami or reservoir failure could also contribute to damage.

Some of these hazards could be additive for buildings in the susceptible areas, as, for example, vibratory damage and sliding damage, vibratory and liquefaction, or vibratory and subsidence. Inundation may or may not add to vibratory damage. However, tsunami effects would not be greatest from local earthquakes so the full combination of tsunami effects and vibratory damage would not be logical.

It is possible although often quite costly to design for resistance to geologic hazards or to greatly mitigate the effects of those hazards. The exceptions are fault rupture and landslides. Fault rupture, fortunately, is not expected within the city limits. Vibratory damage can also be mitigated or completely prevented in design if economically desirable. The various maps can be used with good judgment not only for planning purposes and for emergency preparedness but as an aid in the design of new structures and systems. However, specific studies are recommended for all important structures.

LIFELINES AND EMERGENCY SERVICES

Following a major earthquake disaster, the city's recovery will in no small part depend on restoration of its lifelines and emergency services. Lifelines comprise the city's major utility and transportation systems, and emergency services consist of its fire, police, health, and emergency communications systems. Because all of these systems are so vital to normal operations, disruption of their functions, even for short periods, can jeopardize public welfare and otherwise restrict the city's ability to recover quickly from disaster.

Following the severe damage sustained by lifeline and emergency services systems in the 1964 Alaskan and 1971 San Fernando earthquakes, it became apparent that many such systems located in other seismic areas were similarly vulnerable. Accordingly, to assess the vulnerability of San Francisco's lifelines and emergency services, a survey was undertaken. A questionnaire was sent to the major utility, transportation, and emergency services groups, supplemented by follow-up discussions. The two groups were treated separately because the lifeline facilities are typically more numerous and physically extensive and because emergency services are more closely associated with the immediate post-disaster needs. The groups surveyed are listed below.

Lifelines

Bay Area Rapid Transit District
Department of Transportation, State of California (Highways)
Water Department
Division of Sanitary Engineering, Department of Public Works
Golden Gate Bridge, Highway and Transportation District
Municipal Railway
Pacific Gas & Electric Company
Pacific Telephone & Telegraph Company
Southern Pacific Transportation Company (Railroad)
Toll Bridge Administration, Department of Transportation, State of California (Bay Bridge)

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Emergency Services

Department of Electricity (Communications)
Department of Public Health
Fire Department
San Francisco General Hospital
Police Department

The purpose of the questionnaire was threefold: (1) to determine cognizance of seismic hazards to vital functions; (2) to determine the seismic status of existing vital facilities; and (3) to determine present seismic planning and design procedures for vital new construction. Survey results are presented in Tables 1, 2, and 3 of Appendix C.

Response to the questionnaire showed that all agencies surveyed are aware of their vital functions in a seismic disaster. However, they vary considerably in their knowledge of how seismic hazards will affect their facilities and of what steps must be taken to provide the necessary seismic resistance. A substantial number have not studied the impact of a major earthquake on their facilities, made estimates of expected damage, or developed contingency plans. This is clearly an area for improvement, particularly for the emergency services.

As a group, the emergency services are generally deficient in the adequacy of their seismic planning, hazard abatement, and seismic design, particularly because their services will be the most urgently needed in a disaster. The survey found that from the standpoint of physical facilities, the emergency services group was the least prepared. Planning of new emergency services facilities for post-disaster maintenance of operations shows a strong need for improvement. Likewise, investigation of existing buildings and structures for structural hazards could be improved. There were some exceptions, however, such as the Fire Department's review and upgrading of many of its older buildings in the 1950s, but generally these agencies were found to be using many old structures whose seismic resistance has not been reviewed against modern standards and whose sites had not been investigated for geologic hazards.

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Some changes are forthcoming due to recent state legislation such as SB 519, which places new hospital construction under much more restrictive seismic design requirements than ordinary buildings. This legislation will help mitigate some hazards, but few, if any, extraordinary requirements protect the other emergency services facilities. This is an area in which improvements should be forthcoming.

Regarding lifelines, the survey results indicate that there has been a definite improvement in seismic planning and design procedures for new construction compared to what was done in the past. Many of the new vital lifeline systems are now receiving some form of geologic hazard investigation, and seismic design criteria for structures tends to be above the minimum levels often used in ordinary construction. Three agencies in particular, PG&E, BART, and the Department of Transportation, have or are beginning to utilize dynamic analysis or improved static analysis procedures in seismic design for key facilities. The State Department of Transportation has also begun upgrading its existing aerial structures since the 1971 San Fernando disaster, and some of these structures are being strengthened by restraining ties between adjacent bridge spans in an attempt to prevent complete collapse. However, the 1971 San Fernando experience showed that considerable damage or collapse was also caused by such other factors as abutment soil failures or lack of toughness in bridge piers, which are much more difficult to mitigate once the structure is built.

Many of the underground utilities that traverse the eastern and northern waterfront areas and the Lake Merced area may be subject to outages from pipe breakage due to ground movements, as indicated in "Part I: Geologic Evaluation." Similar distress to underground utilities will probably occur throughout the city, but to a lesser extent. Generally, however, such breakage can be repaired quickly and without any long public inconvenience, but the case of the Auxiliary Water Supply System (AWSS) may deserve special consideration. The AWSS has a network of relatively large-diameter, high-pressure water lines for fire fighting. Many of its lines in the eastern waterfront area traverse areas of potentially

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seismic-unstable ground, and the system and its seawater pumping station should be reviewed in light of this.

Another major area of lifeline concern is the approaches to the bridges that span San Francisco Bay. A report (Department of Transportation, 1973) on the Bay Bridge indicates that if earthquake restrainer units are not installed on the approach spans to the bridge, there is a great possibility of traffic disruption due to misalignment in the event of a major earthquake. The Golden Gate Bridge approaches in the Presidio area need a similar investigation. Both bridges may experience distress at approaches from ground instabilities (NOAA, 1972).

In summary, while present seismic design practices are an improvement over those of the past, not all lifeline and emergency service organizations appear to be uniformly committed to the highest standards of seismic safety. Several of the organizations surveyed are using virtually state-of-the-art design procedures, while many others lag appreciably behind, particularly with regard to post-disaster maintenance of vital functions.

What is needed for the lifeline and emergency services facilities is: (1) definition of the vital facilities and services of each agency; (2) development of minimum siting and seismic design standards for vital new construction, particularly for those facilities whose post-earthquake function is immediately needed; (3) full investigation of existing vital facilities; and (4) hazard abatement. Not only must the site and the structure of a vital facility be highly seismic-resistant, the facility's equipment and building contents must also be protected to insure post-disaster maintenance. Furthermore, a source of emergency power must be provided in each unit and given the necessary seismic resistance. Key facilities should also be located away from structures that may collapse on them.

For the other, less critical lifeline and emergency services facilities, less stringent seismic standards may be imposed, but these should be

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consistent with quick restoration of needed public services. In special cases where designs involve unusual features -- such as large-capacity water storage tanks, where damage from sloshing or wall buckling due to overturning tendencies is possible -- special analysis procedures should be used.

Application of the results of this study to the lifelines should consider the implications of the maps in "Part I: Geologic Evaluation." Possible damage to streets, mass transportation facilities, and to domestic and fire water supplies, sewage, power, and telephone distribution systems can be related to the geologic hazards of subsidence, liquefaction, landsliding, tsunami, and flooding. For example, the tsunami design criteria for the BART facilities should be reviewed in light of the more recent USGS data discussed in Part I. In general, lifelines in the designated hazard zones can be expected to be disrupted, and the impact of possible disruption should be evaluated and mitigated wherever feasible and appropriate.

EARTHQUAKE HAZARDS

The greatest hazard during earthquakes is from falling construction material and the collapse of walls, ceilings, or of whole buildings. No one should be hurt by the shaking per se, although extreme fear can induce physiological or mental injuries in some cases. Such geologic hazards as the massive mudflows in South America or the tsunami action in Japan, Hawaii, or Alaska can cause fatalities. San Francisco does not have major geologic hazards as compared to certain other areas, but it has a severe problem from ground shaking and building damage, especially in areas that might be congested at the time of the earthquake.

With the exception of being in a collapsing building, no doubt the greatest hazard to people is from falling construction materials, especially from parapet walls on building tops and from disloged ornamentation on the exteriors of the buildings. Not only are these items on old buildings not designed to withstand severe motion at upper levels, but there is probable deterioration with age that makes the attachments doubtful even without an earthquake. There is a local parapet ordinance to reduce this hazard gradually but for various extenuating reasons it has not yet been possible for the City Bureau of Building Inspection to begin its enforcement. It is expected that this work will begin by the fall of 1974, but it will take considerable time for the job to be completed.

Buildings constructed before the adoption of a seismic code that have a combination of brittle materials and inadequate connections between horizontal and vertical elements are often very poor risks and may be subject to collapse. Most pre-1948 type C (or type 3) buildings fall into this category and must be suspect unless specifically shown to be adequate. Unfortunately, many of these are multi-unit residential buildings and have high occupancy rates throughout the week, unlike commercial buildings, which are occupied only 40 to 50 hours per week.

Although pre-seismic code classical buildings have had a fairly good record (largely because of the abundant use of nonstructural materials)

and probably would not collapse, they could suffer considerable damage and this could be costly as well as locally hazardous. Most of San Francisco's large public buildings are in this category. The old (1906) City Hall was a loss even before the fire, but the 7th and Mission post office survived, as did the Fairmont Hotel, the original portion of the St. Francis Hotel, the Palace Hotel (until it was burned out), the old Mint building, Fort Point, the old Appraisers Building (now gone), and others.

The damage estimation map, Figure A, should be used together with population densities by the time of day and the day of the week to estimate fatalities in the most hazardous areas. Obviously, a major earthquake at 12:00 noon is a much different problem than one at 2:30 a.m.

In addition to fatalities and injuries from building damage per se, there are various other seismic hazards from movement or overturning of building contents (stored goods, books, files, furniture, etc.); elevators jamming or malfunctioning; blocked or broken stairways; jammed doors; broken glass due to building distortion or direct impact; smoke and fire; loss of emergency power; and panic. There are also problems of vehicular movement in blocked streets, loss of water and sanitary systems, and broken gas lines. Emergency hospital facilities may be impaired or out of service because of loss of supplies, utilities, and possibly also standby equipment that was not well secured to its supporting elements. An overall pre-earthquake systems approach to these problems could be most effective in disaster mitigation.

Destructive earthquakes cause not only potentially great casualties but also property losses. There is also severe impact on business and possibly on property values if damage is extensive. It is not generally realized that some of the impact and losses are spread to the state or the country as a whole through relief and reconstruction costs, business losses, insurance costs, tax losses, and in other ways.

Assessment of Building Hazards

Injury and loss of life from earthquakes in San Francisco would be largely the result of building damage. It is extremely difficult to

quantify such a hazard to persons in and about buildings. The obvious limits of a seismic risk scale range from no risk when there is no damage to death of almost the entire population where all the buildings collapse. Intermediate points on such a scale would bear some relationship between the amount of damage and the injuries and deaths to those in and about the buildings.

It is quite possible that people could be injured or killed with relatively minor building damage. For example, persons on the sidewalks and the streets may be struck by construction materials falling from building parapets and ornamentation. Glass may also fall from a building and create a hazard. Old buildings designed without earthquake-resistant characteristics and having considerable ornamentations and appendages, whose anchorages have no doubt deteriorated with time and exposure, are especially hazardous in this regard.

Occupants of buildings that do not collapse or suffer partial collapse are still subject to death or injury from materials falling from the ceilings or walls, moving furniture or stored goods, not to mention problems arising from blocked stairways, malfunctioning elevators, and possible fire and smoke.

The least hazardous type of building is the small, wood-frame residence on stable soil and free of geologic hazards except shaking. Very few persons should be killed in such structures even in violent earthquake motion. Some injuries and deaths are, of course, possible even in the slight damage level areas of Figure A. Flats on narrow lots are considered more hazardous unless specially braced in the transverse direction.

The most hazardous areas of the city are those areas designated as having severe damage levels in Figure A. Persons in and about the typical buildings in blocks rated severe would be subject to many hazards whether on the streets near buildings or in the buildings. Of course, there could be some safe buildings even in the severe-rated blocks, as previously discussed. Some buildings could collapse partially or completely and kill most if not all those in the region of collapse. Based on judgment and

meager data, loss of life in the severe-damage-level areas could average 1% or more of the area population.

The heavy damage level of Figure A would be less hazardous to persons than the severe level, except for those in the streets near multi-story buildings who could be subject to essentially as much falling debris. There would be less hazard of collapse, although walls could fall out and be quite hazardous locally, and ceilings could fall.

The moderate damage levels of Figure A would offer less hazard than either heavy or severe but considerably more than the slight category.

The slight damage level would not be generally hazardous. However, a few accidents and possibly deaths could occur from the severe shaking and unfortunate and improbable circumstances.

Injuries requiring hospitalization from all damage areas would be many times the number of fatalities. A figure of 10 to 15 times fatalities would be a reasonable estimate.

Economic loss, from both property damage and business disruption, would also vary with the ratings in Figure A. The average losses would essentially follow the damage level ratings -- namely, severe, heavy, moderate, and slight -- based, of course, on a 1906 type earthquake with no major fire.

There is insufficient information available to make refined estimates of deaths, injuries, and damage costs regardless of the procedures and mathematics employed. The following are crude estimates, not predictions, based on sparse history and judgment. They are for average conditions in a 1906 type earthquake affecting December 1973 buildings assumed to be on stable soil. Geologic hazards and nonbuilding damage would be additional factors.

Damage Level Figure A	Estimated Average Percentage of those in Area at the Time		Estimated Average Property Loss as Percentage of Replacement Cost
	Deaths	Injuries Requiring Hospitalization	
Severe	1.0%	15%	75%
Heavy	0.3%	4%	50%
Moderate	0.1%	1%	25%
Slight	0.02%	0.2%	5%

With the above seismic risk scale, Figure A, and census tract data on population deployment at various times of the day and days of the week, rough estimates of fatalities and hospitalized injuries from building damage can be made. Economic losses can also be estimated with information on replacement costs. Such estimates were beyond the scope of this investigation, as was a study of probabilistic aspects of the problem.

The risk from severe earthquake motion in San Francisco is high in two respects. First, there is a high probability that severe, damaging earthquakes will occur in a given period of time, almost certainly within the life span of most of the buildings now existing. Second, many of the buildings are not adequately resistant to earthquake motion. The result will be loss of life, injuries, and severe economic losses from property damage and business disruption.

Although any unnecessary loss of life is deplorable, there is some risk in almost all human endeavors. There is no such thing as absolute safety, and what constitutes an acceptable risk to one person may not be acceptable to another. A definition of acceptable risk that has some logical appeal is that level of risk which a reasonable person, informed of all the facts and given the choice, would not try to reduce further by investing more money or effort to gain greater risk reduction. On a public matter, this would of course be related to the majority preference. People generally expect buildings to be safe under all conditions. If they are not, people should be so informed.

The basic objective behind this investigation is to reduce earthquake hazards. This shall be considered in two parts -- the reduction of future hazards not now existing, and the reduction of existing hazards.

Reduction of Future Building Hazards

This is the easier task from the viewpoints of economics and social impact. It involves both planning and building codes. Planning for a limited area such as San Francisco should involve avoiding uncontrollable geologic hazards in siting and, because space is limited, replacing poor risk buildings by good buildings.

The building codes should insure that all new construction has adequate earthquake resistance. The present San Francisco seismic code is considered good, but it should change in the future as new information and new design criteria are found to be useful, reliable, and acceptable. The word

"acceptable" involves economic as well as technical constraints. Consideration should be given to code provisions that allow for vital inelastic behavior and energy absorption capacity. It is, of course, basically important that the construction follow the design specifications in all respects and that the design meet or exceed the code requirements in all respects.

New public assembly buildings and buildings housing such emergency services as police, fire, ambulance, hospital, bloodbanks, emergency and medical supplies, and vital records should be designed for greater resistance than now required by the San Francisco code for ordinary private buildings. The degree of greater resistance should be the subject of a special study that would consider recent state legislation and the results of recent earthquakes and recent research.

Reduction of Existing Building Hazards

The problem of existing poor-risk buildings is a difficult one, involving serious economic and social problems. It is not possible to require the abrupt strengthening or demolition of a privately owned building without causing financial hardship to the owner. On the other hand, something needs to be done where lives are involved in those cases in which the inadequacy has been established on a specific basis.

A basic step lies in the area of city planning. The earthquake hazards suggested in Figure A should be integrated with all the other factors in city planning to arrive at master planning that will accelerate the elimination of poor structures in an orderly manner and without severe economic distress. A splendid example of progress is the Yerba Buena Center that will replace high-risk, low-income buildings with good buildings that will have great economic value to the city. There are, of course, many other examples of area improvements in San Francisco and elsewhere.

The strengthening or demolition of specific buildings could be approached on a time/step basis wherein certain progressive steps are taken on a time schedule. The steps would begin with specific investigations of

suspect buildings which, if the buildings did indeed turn out to be high-risk cases, would lead to vacating, strengthening, or razing the buildings as may be indicated. The owner would be given certain options and time periods to carry them out so as to reduce the economic impact as much as possible. In most cases this procedure would lead to replacement by better buildings, assuming there was demand for building space.

An example outline of such a program for certain private buildings follows. The actual program would require detailed study.

Step No.	Item	Time Schedule
1.	Qualified engineers investigate on a walk-through basis pre-code type C buildings that fall in the severe damage areas of Figure A and/or are in the highest residential density blocks of Figure B. Categorize these specific buildings into seismic risk classes as to code violations, risk to occupants, and structural condition. Give a copy of the findings to the owner together with an appropriate first notice of his options.	To be completed as soon as available personnel (building inspectors or consulting engineers) permit.
2.	Give those buildings that were determined in Step No. 1 to be the most hazardous to occupants and have high occupant density a detailed investigation by a structural engineer, paid for by the owner, and give the report to the owner and to the city. Send an appropriate second notice to the owner.	To be completed within one year after first notice to owner.
3.	Require those buildings determined in Step No. 2 to constitute serious safety hazards to be rehabilitated or to be vacated or demolished.	To be completed within five years of second notice to owner.

A similar program could be carried out for various types of buildings with the following suggested priorities:

1. Pre-code buildings of any type used for bloodbanks, medical and emergency supply storage, hospitals, ambulance storage, medical centers, police stations, firehouses, or communication or emergency centers.

2. Pre-code type C buildings used as retirement homes, convalescent homes, orphanages, schools, nurseries, or jails.

3. Pre-code type C buildings of high living unit density as per Figure B.

4. Pre-code type C public buildings other than the above, especially those with meeting rooms or places of assembly.

5. Pre-code type C residential buildings other than the above as per Figure B and nonresidential pre-code type C buildings of high block density as per Figure C.

6. All other buildings in severe damage areas of Figure A.

7. Selected buildings in heavy damage areas of Figure A.

Multi-unit residential buildings, whether public or private, are of particular concern because of their high occupancy rate; i.e., they are used by people more hours of the week than most other buildings. The following figures are occupancy factors (Blume, 1971) defined as the average ratio of the total person-occupancy hours per year to the product of all the hours in a year times the person-capacity of the building in normal use.

Theatres, churches, arenas	0.04
Schools, colleges	0.20
Offices, shops, factories	0.25
Warehouses	0.25
Hotels (first class)	0.36
Hospitals, rest homes, asylums	0.60
Residences	0.62
Jails	0.89

Because earthquakes can occur at any time, the exposure varies with the occupancy factor times each building capacity. Theatres, churches, and

arenas have a low average occupancy factor but high capacity. Residential buildings have a high occupancy factor and, if multi-unit and of pre-code construction, especially of type C, they also have a high capacity and are seriously vulnerable to earthquakes. They should be investigated on a case-by-case basis if their occupancy is to be continued.

SUMMARY AND RECOMMENDATIONS

San Francisco is clearly subject to major earthquakes, and there will be considerable damage and many fatalities when these major earthquakes occur. However, buildings in San Francisco are generally more resistant to earthquake motion, and there are lesser geologic hazards than in certain other countries where there has been tremendous loss of life from earthquakes. Some San Francisco buildings are good risks, while others are not.

By no means did all of the San Francisco buildings fail in 1906. Some 25,000 of them are still in use in spite of both the 1906 earthquake and the fire. However, most of these buildings were constructed with heavier nonstructural materials and elements than contemporary buildings. Although they would not be able to meet current seismic code requirements, many are, in a random way, quite strong and resistant. In general, however, buildings built before the first San Francisco earthquake code of 1948 have less resistance than buildings built in 1948 or later. Some of the pre-code buildings built after the 1906 earthquake and before the 1948 code are considered to be subject to severe damage with some collapses.

Areas of great potential damage can be upgraded with the aid of planning. High-risk buildings can eventually be replaced by buildings of low seismic risk, hopefully without severe economic consequences. Isolated cases of apparent high risk can be strengthened or replaced by new structures. Although the damage level estimates shown in Figure A for a great earthquake like that in 1906 should be generally useful, the map is based on statistical analysis and should be supplemented by structural analysis of specific buildings of interest; these buildings may vary considerably from the statistical models.

There is no known indication of potential fault rupture or movement within the city limits. However, the active San Andreas fault lies

just west of the city under the Pacific Ocean. This fault caused the great 1906 earthquake and the mild 1957 earthquake. It can be expected to cause other earthquakes at any time or times in the future. In addition, San Francisco is subject to shaking from disturbances originating on the Hayward and other faults east of the bay. Preparations should be made for one or more damaging earthquakes before the year 2000.

No building or structure should be designed and constructed without regard for possible geologic hazards. Although most of these hazards can be tolerated or designed for in San Francisco, the possibility of landslides in certain portions of the city under severe earthquake motion should be given serious attention.

The various maps in the report can be used to aid in planning the future development or improvement of the city. Figures A, B, and C can also be used as aids in reducing existing earthquake hazards with a time/step program, as outlined in the report, to gradually reduce or eliminate the worst building hazards. For each item in the list of hazard reduction priorities presented earlier, a total period of about six years is suggested in the time/step program in which to reduce or eliminate the worst hazards to life. Hopefully, several priorities could be handled concurrently in appropriate steps.

Figures B and C show the type of building construction that has earned a poor reputation for performance in strong earthquakes. This is type C construction built prior to seismic building codes, defined herein as buildings built before 1948 with exterior masonry or concrete bearing walls connected by wood floors and/or a wood roof. Figure B is for living unit density and Figure C for nonresidential building density. Although some of these buildings may be found to be quite strong under specific analysis, the statistical record is poor and the buildings should be considered suspect until shown to be adequate.

It is also suggested that a typical San Francisco condition could be improved at minor cost. This is the two- or three-story building that

consists of flats; it is on a narrow lot, has a stairway and a generally open garage with a wide garage door. In those buildings that have little resistance in the transverse direction of the lower story, more bracing could be provided in the form of walls, partitions, and/or knee braces. Typical details could be developed for general use. Many old frame buildings have had garage doors cut into them and could also be braced at low cost. Such frame buildings are rated in the study as having slight damage because it was not practical to isolate them. They could be quite resistant if braced.

The city should be continuously interested in the condition and earthquake resistance of its elevated freeways and bridge approaches as well as its own bridges. In the event of a disaster in San Francisco, the use of the freeways and bridges would be vital in bringing in emergency supplies and personnel and in transporting the injured and others elsewhere. Transportation is vital after a major earthquake in an urban area.

The utility and communication lifelines are also vital after a major earthquake, and yet they will be disrupted. Emergency services are even more vital. The survey conducted as part of this study indicates that not all controlling agencies are fully aware of their basic functions in an earthquake disaster. Hopefully, this survey has helped to emphasize this aspect of the earthquake problem. Several companies or agencies have not studied in adequate detail the impact of a major earthquake on their facilities and services, nor have they made adequate contingency plans, especially for critical emergency services. Fire drills and lifeboat drills may become boring, costly, or both, but they are essential for survival. Each agency or utility should have its plans and its drills, and some of them should also pay more attention to prevention of earthquake damage and loss of service.

The San Francisco building code is a good one and, in fact, it is better in certain respects than in most other seismic areas. Like any code, it needs updating from time to time as new, demonstrated, and acceptable

technologies or materials are developed. However, there was no local seismic code (except for the minimal Riley Act of 1933) before 1948 and that fact is obvious throughout this report. Building codes need enforcement, and that requires financial support. San Francisco could well consider increased support of its Department of City Planning, Bureau of Building Inspection, and other agencies concerned with earthquake resistance, utility services, and emergency support for earthquake disasters.

Finally, this type of study should be repeated after a period of about 10 years to account for the changes in San Francisco's buildings, new technology and state-of-the-art, any intervening earthquakes, and to compare San Francisco's earthquake potential at that time with its present potential. Hopefully, much progress will have been made. San Francisco is not "the city waiting to die" -- it is active in preserving itself for the future.

APPENDIX A

Technical Information on Damage Estimation

APPENDIX A

TECHNICAL INFORMATION ON DAMAGE ESTIMATION

Appendix A contains information that supplements the damage estimation procedures and assumptions used in this study. Because the anonymity of specific buildings is to be preserved, complete details and data on procedures are not released.

In general, the procedure followed after extensive initial investigation was to develop spectral response diagrams for various parts of San Francisco, with allowances for deep, soft site materials; to assign natural periods to the various classes of buildings, first in the undamaged elastic state and then in an assumed damaged state with only the structural elements providing resistance; to select spectral accelerations from the diagrams based on these periods; and finally to assess damage based on the estimated resistance to these spectral accelerations. This was done for every building in the city for which there were adequate data in the Assessor's records except for type F and S buildings, which were considered only on the basis of peak ground acceleration.

The Ground Motion

Ground motion can be considered in various ways. It is often evaluated by its peak amplitude in terms of acceleration, velocity, or displacement. Sometimes all of these are included in a description. From the viewpoint of structural response, a peak amplitude value without consideration of the frequency content and duration of the motion generally constitutes an inadequate definition. A much more meaningful criterion is a response spectrum made from the entire recorded time history of the ground motion. However, no strong motion records were made of the 1906 San Francisco earthquake or for decades after 1906. Thus, specific knowledge about peak motion or spectral response is not available for the 1906 earthquake.

In the period since 1906 and especially in recent decades, much has been learned about the relationships of magnitude, epicentral distance, focal depth, soil conditions, ground shaking characteristics, and intensity.

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Information has been used in this study, together with the excellent documentation of 1906 earthquake effects by Wood (1908), to develop various possible acceleration response spectra for the city under repetition of the 1906 earthquake. Figure 3 of "Part I: Geologic Evaluation" shows the relative intensities as estimated from the Wood report, which used, five intensity levels, A, B, C, D, and E. The next step was to assign peak acceleration values to each of these intensities after considerable study and the realization that unknown frequency effects and soil conditions give this step some degree of uncertainty. However, the Wood survey was a painstaking one that attempted to evaluate both structural and geologic effects. The values finally assigned for use in this investigation are as follows:

Wood Rating	Assumed Peak Acceleration
A	0.7g*
B	0.6g
C	0.5g
D	0.4g
E	0.3g

*g represents the acceleration of gravity

The next step was to assign dominant ground periods over the city, depending on the softness and the depth over rock of soil deposits or fill materials. The deep, soft materials were assigned average natural periods as long as 2.3 seconds. The variations over the city were considerable, especially around the waterfront and where there had been creeks or sloughs in years past. Altogether, six categories of soil conditions were assigned which, coupled with the five Wood ratings, led to 30 possible response spectra. Some of these, however, did not apply. For example, only a very small corner of the city was rated A and that portion does not have all six site period situations. The soils were divided into two types, artificial fill over bay marshlands and medium-dense sand. These types were then subdivided into groups, depending on depth, with characteristic site periods as follows:

Soil Depth (ft)	15 Ft of Fill Over Soft Clay (sec)	Medium-Dense Sand (sec)
100	1.1 to 1.7	0.6 to 1.0
200	1.5 to 2.3	1.0 to 1.5
300	2.0 to 2.5	1.4 to 2.0

The above values correspond to those published in the Stuctural Engineers Association of Northern California News (1973). Soil shallower than that listed was considered to be provided for by the average response spectra used in the study.

Advantage was then taken of an intensive study made on spectral shapes for the Atomic Energy Commission (Blume, Sharpe, and Dalal, 1973; Newmark, Blume, and Kapur, 1973). In this study, the shapes of response spectra for various damping ratios and for various probabilities of occurence were developed from a study of 33 strong motion records. The spectra were normalized to gravity for this analysis. The data were combined statistically and idealized into smooth spectral curves that are now AEC standards. For this San Francisco study, 5% damping was used together with the mean values of spectral shape to represent response spectra after denormalization to the proper peak ground acceleration. The curves then obtained were considered valid only to a period of 0.50 seconds. Beyond 0.50 seconds, spectral adjustments, or "humps," were provided for the local characteristic site periods previously discussed.

The resulting spectral curves were digitized, identified with each block in San Francisco, and used as input for the computer analysis. Again, the values are for the mean condition and could thus vary considerably, up or down, from the mean. It was not feasible in this program to work directly with probabilistic variations.

Building Characteristics

Buildings were treated in the five classes provided in the Assessor's records, as described earlier in the section on San Francisco building codes and building types. Types A, B, and C were analysed on a statistical basis with the use of response spectra and natural periods, and damage for types S and F was obtained with reference to peak ground

acceleration and assigned damage factors. Types A, B, and C were also divided into two groups, those built before 1948 and those built in 1948 or later. The year of construction was available for each building in the Assessor's records. Although there have been many changes and improvements in code requirements over the years since 1948, such refinements were felt to be beyond the needs or values of this damage study, which does not include specific analysis of buildings. The major change from essentially no seismic forces to comprehensive lateral force design occurred in 1948.

The natural fundamental periods were assigned as a function of the number of stories, N, as follows:

	Initial Period (sec)	Final Period (sec)
Pre-1948, Type A building	0.07N	0.17N
Pre-1948, Type B building	0.06N	0.12N
Pre-1948, Type C building	0.05N	0.09N
1948 or later, Type A building	0.10N	0.18N
1948 or later, Type B building	0.08N	0.16N
1948 or later, Type C building	0.05N	0.10N

The relative damage scale for a given spectral acceleration, for both the initial stage and the final stage, was determined only after extensive study of actual earthquake damage, theory, and much analysis. It is as follows:

Pre-1948, Type A building	1.67
Pre-1948, Type B building	2.34
Pre-1948, Type C building	3.00
1948 or later, Type A building	1.00
1948 or later, Type B building	1.16
1948 or later, Type C building	1.34

Note that the damage per se varies strongly with the spectral acceleration at the fundamental period of the building. Therefore, most low buildings with shorter periods and thus greater spectral accelerations would suffer more damage (relative to the taller buildings) than the relative scale alone would suggest.

These relative ratings were used together with a constant and a power of the 5%-damped spectral acceleration corresponding to the fundamental period of each structure to estimate damage ratios and damage levels for block averaging and plotting. Buildings of very large base area were also assigned a reduction factor because of their better experience record.

APPENDIX B

San Francisco Seismic Risk Survey
Census Tract Distribution of Pre-Code
Type C Buildings

APPENDIX B

SAN FRANCISCO SEISMIC RISK SURVEY

CENSUS TRACT DISTRIBUTION OF PRE-CODE TYPE C BUILDINGS

1970 Census Tract Number	Quantity of Residential Units	Quantity of Residential Buildings	Quantity of Nonresidential Buildings
101	0	1	16
102	434	13	12
103	77	3	3
104	19	2	6
105	6	3	53
106	144	31	53
107	181	20	17
108	79	3	3
109	144	5	10
110	102	4	23
111	269	18	33
112	161	9	0
113	637	60	14
114	742	94	51
115	169	36	107
116	0	0	6
117	1516	37	212
118	511	52	37
119	1465	52	7
120	2035	89	40
121	2602	94	36
122	3388	130	65
123	3712	93	41
124	3804	103	84
125	3976	76	58
126	43	1	18
127	0	0	0
128	2	1	3
129	135	3	2
130	201	7	8
131	1559	83	8
132	328	17	2
133	40	4	4
134	131	5	3
135	257	10	3

1970 Census Tract Number	Quantity of Residential Units	Quantity of Residential Buildings	Quantity of Nonresidential Buildings
151	316	11	30
152	256	14	10
153	36	2	8
154	0	0	5
155	226	3	13
156	0	0	3
157	0	0	1
158	0	0	6
159	179	4	22
160	423	8	19
161	278	7	9
162	497	15	24
163	0	0	6
164	114	3	7
165	36	1	4
166	0	0	8
167	59	2	1
168	725	16	20
169	3	1	2
170	0	0	0
171	40	1	5
176	490	60	385
177	0	0	70
178	145	9	284
179	9	3	150
180	112	2	168
201	417	19	82
202	39	4	17
203	24	1	9
204	0	0	0
205	0	0	2
206	0	0	2
207	2	1	4
208	88	7	38
209	55	1	23
210	55	2	3
211	0	0	1
212	1	1	0
213	0	0	0
214	0	0	0

1970 Census Tract Number	Quantity of Residential Units	Quantity of Residential Buildings	Quantity of Nonresidential Buildings
215	0	0	3
216	0	0	0
217	0	0	0
218	0	0	0
226	2	1	21
227	468	4	19
228	8	2	52
229	0	0	5
230	6	1	1
231	0	0	7
232	0	0	1
233	0	0	13
234	0	1	4
251	0	0	9
252	2	1	4
253	0	0	7
254	0	0	3
255	21	1	3
256	0	0	0
257	0	0	6
258	0	0	0
259	0	0	0
260	0	0	5
261	0	0	2
262	2	1	0
263	46	5	2
264	0	0	0
301	0	0	1
302	35	1	5
303	0	0	1
304	0	3	1
305	0	0	0
306	0	0	0
307	0	0	0
308	33	2	15
309	0	0	3
310	0	0	0
311	0	0	1
312	0	1	6
313	0	0	0

1970 Census Tract Number	Quantity of Residential Units	Quantity of Residential Buildings	Quantity of Nonresidential Buildings
314	0	0	1
326	33	2	2
327	0	0	0
328	0	0	3
329	2	1	2
330	0	0	3
331	0	0	0
332	327	6	0
351	0	0	3
352	0	0	1
353	0	0	1
354	20	2	1
401	0	1	7
402	0	0	14
426	36	1	10
427	53	2	5
428	12	2	0
451	27	2	2
452	90	4	4
476	0	0	1
477	34	1	2
478	0	0	0
479	94	3	2
601	0	0	0
602	0	0	0
603	0	0	1
604	0	0	0
605	0	0	0
606	0	0	0
607	0	0	31
608	0	0	8
609	0	0	11
610	0	0	2

PACIFIC OCEAN
SAN FRANCISCO BAY
601 PRESIDIO
603 GOLDEN GATE PARK
604 LAKE MERCED
605 JOHN McLAREN PARK
606
607
608
609
610
LINCOLN
GEARY
POST
SUTTER
BUSH
PINE
CALIFORNIA
SACRAMENTO
CLAY
WASHINGTON
JACKSON
PACIFIC
BROADWAY
VALLEJO
GREEN
FILBERT
CHESTNUT
LOMBARD
LOMBARD CREEK
WEST PACIFIC
LAKE
CALIFORNIA
PRESIDIO
JEFFERSON
MARINA
BAY
LEAVENWORTH
HYDE
LARKIN
POLK
VAN NESS
FRANKLIN
GOUGH
OCTAVIA
LAGUNA
BUCHANAN
WEBSTER
FILLMORE
STEINER
PIERCE
SCOTT
DIVISION
SOUTH VAN NESS
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602nd
ALEMANY
ARMY
BAYSHORE
BRYANT
CASTRO
CHENERY
CLEMENTINA
CLIPPER
DOLORES
DUBOCE
EUCALYPTUS
FELTON
FOLSOM
FULTON
GRAND VIEW
HARRISON
HAYES
HOLLOWAY
HOWARD
INDUSTRIAL
JUDAH
KANSAS
KIRKWOOD
LAKEVIEW
LINCOLN
MANGELS
MARKET
MARKET OCTAVIA
MISSION
MONTEREY
MORAGA
NOE
OCEAN
ORTEGA
PACHECO
PALOU
PARNASSUS
PORTOLA
QUINTARA
RANDALL
SAN JOSE
SAN MATEO
SANTOS
SILVER
SOUTHERN FREEWAY
ST FRANCIS
ST MARYS
TARAVAL
TEMESCAL
TOWNSEND
TURK
UNIVERSITY
VICENTE
WAWONA
WILLOWBROOK
YERBA BUENA
YORKTOWN
YOSEMITE
1970 CENSUS TRACTS

APPENDIX C

Summary of Response to the Lifelines and Emergency Services Survey

TABLE 1

AWARENESS OF SEISMIC HAZARDS

Agency has:	Lifelines		Emergency Services	
	Yes	No	Yes	No
Awareness of its role in providing vital services following earthquake disaster	10	0	5	0
Studied the impact of a major earthquake on its facilities	5	5	1	4
Developed predictions of probable earthquake damage to its facilities	4	6	0	5
Developed contingency plans for post-earthquake operations	5	5	4	1

TABLE 2

SEISMIC STATUS OF EXISTING VITAL FACILITIES

Geologic Hazards Agency has investigated the sites of its existing vital facilities for the following:	Lifelines		Emergency Services	
	Yes	No*	Yes	No
Faulting, ground rupture	7	3	1	4
Landslides	6	4	3	2
Tsunami or seiche	3	7	1	4
Liquefaction	4	6	1	4
Motion-induced ground consolidation or settlement	3	7	1	4
Ground consolidation or settlement under static conditions	9	1	3	2
Ground shaking	5	5	1	4

Structural Hazards Agency has investigated existing facilites, where applicable, for the following:	Lifelines		Emergency Services	
	Yes	No	Yes	No*
Safety of pre-Riley Act (1933) structures	1	5	1	4
Deterioration of buildings due to settlement	2	4	3	2
Deterioration of buildings due to age	1	6	3	2
Safety of older masonry structures	1	3	3	2
Adequacy of lateral force systems under present code requirements	1	5	0	5
Adequacy of lateral force systems under rational, as compared to code, seismic criteria	1	6	0	5

* No, or no answer given

TABLE 3

PRESENT SITING AND DESIGN
PROCEDURES FOR VITAL NEW CONSTRUCTION

Investigation of Geologic Hazards	Lifelines		Emergency Services	
	Yes	No	Yes	No
Faulting, ground rupture	8	2	4	1
Landslides	6	4	4	1
Tsunami or seiche	5	5	4	1
Liquefaction	8	2	4	1
Motion-induced ground consolidation or settlement	7	3	4	1
Ground consolidation or settlement under static conditions	8	2	4	1
Ground shaking	8	2	4	1

Seismic Design Criteria	Lifelines	Emergency Services
S. F. Code	4	4
S. F. Code plus	1	-
State Code	3	1
Dynamic Analysis	2	-

Planning for Continued Operations	Lifelines	Emergency Services
In planning new facilities, consideration is given to post-disaster maintenance of vital operations	8-Yes 1-No 1-No Answer	3-Yes 2-No Answer

APPENDIX D

Data From Other Investigations of San Francisco Bulkings

APPENDIX D

DATA FROM OTHER INVESTIGATIONS OF SAN FRANCISCO BUILDINGS

There have been various estimates of damage and casualties from the next big earthquake, including a movie, called "The City That Waits To Die." Most of these estimates are for the whole San Francisco Bay Area and nearly all of them are of a general nature without detailed consideration. Some predictions of losses are in the billions of dollars and tens of thousands of lives. All estimates have recognized the importance of the downtown population density at the time of the big earthquake.

Two reports have included specific data on San Francisco buildings, one for the Department of Housing and Urban Development (HUD) and one for the Office of Emergency Preparedness (OEP); both reports were by the U.S. Department of Commerce (ESSA/HUD, 1969; NOAA/OEP, 1972). The data that follow have been excerpted from these works.

The Report for HUD

The U.S. Department of Commerce made an extensive study (ESSA/HUD, 1969) for the Department of Housing and Urban Development of damage to residential wood-frame buildings having not more than four living units. Note that wood-frame dwellings are generally much more resistant to earthquake motion than other types of buildings. The study involved total damage to all affected units for a repetition of the 1906 earthquake and of the 1933 Long Beach earthquake. Also considered were probable earthquakes over a 100-year time period and the resulting cumulative damage. 1960 census data and census tracts were used, with costs as of 1968.

Although not specifically released in the report, estimated data for San Francisco were obtained through the courtesy of the investigators, Dr. S. T. Algermissen and Mr. W. Rinehart, now with the U.S. Geological Survey (USGS). Some of this information follows in these figures for damage to residential wood-frame buildings for a repetition of these earthquakes.

Living units	150,000
Units damaged by 1906 earthquake repetition	126,000
Value of risk (1968)	$2,450,000,000
Dollar loss (1968)	$ 119,000,000
Percentage damage	4.85%
1906 Modified Mercalli (MM) intensities in San Francisco	VII, VIII, and IX

For the entire affected area rather than just San Francisco, the 1906 earthquake repetition in 1968 was estimated as follows:

Living units damaged	1,260,000
Dollar loss (1968)	$1,160,000,000

Average damage loss from the ESSA/HUD work is as follows:

Modified Mercalli Rating	Loss Percentage
V	0.07%
VI	0.33%
VII	1.36%
VIII	5.90%
IX	8.80%
X	88.50%

Another estimate is that San Francisco would suffer a total of $314,000,000 of loss to the same wood-frame residential dwellings (1968 costs) over a 100-year period that would involve several earthquakes. Total units damaged would be 769,000 as compared to 150,000 actual, indicating multiple damages in the 100-year period.

The extent of specific damage can be estimated by considering the following deductible (insurance) estimates:

Deductible Amount	Loss in 100 Years
$1000	$ 54,800,000
500	89,600,000
250	150,000,000
100	238,000,000
None	315,000,000
1%	191,000,000

The Report for OEP

Another report was made by the U.S. Department of Commerce, NOAA, for the Office of Emergency Preparedness (NOAA/OEP, 1972). This was concerned with earthquake losses in the San Francisco Bay Area with special emphasis on estimating damage to facilities critically pertinent to disaster relief and recovery. For this study, earthquake shocks with magnitudes 8.3, 7.0, and 6.0 were assumed to occur on the San Andreas fault near San Francisco and also on the Hayward fault near Hayward.

The following information for San Francisco only is taken from this report. San Francisco in 1971 had 19 general hospitals with a total bed capacity of 8040, 1 military hospital with 900 beds, 1 mental hospital with 105 beds, and 1 VA hospital with 409 beds, which totals 22 hospitals with 9454 beds. There were also 32 nursing homes with 2134 beds. In 1970, San Francisco was reported to have 3033 physicians and surgeons, 104 podiatrists, 47 veterinarians, and 5611 registered nurses.

San Francisco is shown in the report to have 11 major pre-1933 hospitals, 7 1933-1960 hospitals, and 4 1960-1970 hospitals. Of these buildings, 6 are one to four stories high and 16 are five to eight stories. The hospital buildings are shown as 13 of concrete, 3 of steel, 3 of brick, and 3 of mixed construction.

The deaths in the hospitals are estimated to be 555 if the 8.3 magnitude earthquake occurs nearby on the San Andreas fault at 2:00 p.m. or 4:30 p.m. and 233 if it occurs at 2:30 a.m. If the 8.3 magnitude

earthquake were on the Hayward fault, the fatalities are estimated to be only 19 at 2:00 p.m. or 4:30 p.m. and 8 at 2:30 a.m. This indicates, as would be expected, that the San Andreas fault is much more of a hazard to San Francisco than the Hayward fault, especially considering the fact that an 8.3 magnitude earthquake would probably not occur on the Hayward fault.

The injuries in hospitals estimated for the 8.3 magnitude earthquake nearby on the San Andreas fault occurring at 2:00 p.m. or 4:30 p.m. in San Francisco is 2874. This figure is reduced to 1208 if the same earthquake occurs at 2:30 a.m. The hypothetical 8.3 magnitude earthquake on the Hayward fault is estimated to cause 272 injuries and 114 injuries for the two time periods, respectively.

Hospital bed losses in San Francisco for the San Andreas fault 8.3 magnitude earthquake are 5970, and 404 for the same size earthquake on the Hayward fault. The report also estimates a 60% to 70% loss of medical supplies from an 8.3 magnitude earthquake.

San Francisco is estimated to have 77 clinical laboratories, 23 of which are in hospitals. Of the 77, 35 are pre-1933 construction, 10 are 1933-1950, 25 are 1950-1968, and 7 are post-1968. The functional loss of laboratories in nonhospital locations is estimated to be 60% in San Francisco and San Mateo counties from the 8.3 San Andreas earthquake.

Following is the report inventory of San Francisco multi-story buildings.

Material	Stories	Number of Buildings	Floor Area (in thousands of square feet)
Concrete	4-8	627	28,550
Concrete	9-13	74	5,949
Concrete	>13	40	9,361
Steel Frame	4-8	399	19,932
Steel Frame	9-13	89	10,800
Steel Frame	>13	62	18,659

Brick	4-8	132	14,181
Brick	9-13	1	58
Brick	>13	0	0
Mixed Construction	4-8	129	4,224
Mixed Construction	9-13	1	79
Mixed Construction	>13	0	0
		1554	

For nighttime hours, an 8.3 magnitude earthquake is estimated to cause the following number of deaths per hundred thousand population in:

1-unit wood frame dwellings	12
2-to-9-unit modern structures	18
2-to-9-unit older structures	26
10-or-more-unit modern structures	64
10-or-more-unit older structures	500

The report shows 16 federally owned buildings including post offices in San Francisco, 7 of which have emergency power.

The report shows 44 fire stations in San Francisco, most of which have been built or strengthened since 1950. It was estimated that 10 fire stations would receive significant earthquake damage or be affected by neighboring building damage with an 8.3 magnitude earthquake.

APPENDIX E

The Intensity Scale
Used by Wood for
the 1906 San Francisco Earthquake

APPENDIX E

THE INTENSITY SCALE USED BY WOOD FOR THE 1906 SAN FRANCISCO EARTHQUAKE

A. Very Violent. Comprised the rending and shearing of rock masses, earth, turf, and all structures along the line of faulting; the fall of rock from mountain sides; numerous landslips of great magnitude; consistent, deep, and extended fissuring in natural earth; some structures totally destroyed.

B. Violent. Comprises fairly general collapse of brick and frame buildings when not unusually strong; serious cracking of brick work and masonry in excellent structures; the formation of fissures, step faults, sharp compression anticlines, and broad wave-like folds in paved and asphalt-coated streets, accompanied by the ragged fissuring of asphalt, the destruction of foundation walls, and underpinning structures by the undulating of the ground; the breaking of sewers and water mains; the lateral displacement of streets and the compression, distension, and lateral displacement of streets; and the compression, distension, and lateral waving or displacement of well-ballasted streetcar tracks.

C. Very Strong. Comprises brick work and masonry badly cracked, with occasional collapse; some brick and masonry gables thrown down; frame buildings lurched or listed on fair or weak underpinning structures, with occasional falling from underpinning or collapses; general destruction of chimneys and of masonry, brick, or cement veneers; considerable cracking or crushing of foundation walls.

D. Strong. Comprises general but not universal fall of chimneys; cracks in masonry and brick work; cracks in foundation walls, retaining walls, and curbing; a few isolated cases of lurching or listing of frame buildings built upon weak underpinning structures.

E. Weak. Comprises occasional fall of chimneys and damage to plaster, partitions, plumbing, and the like.

APPENDIX F

Wechsler-Bellevue Intelligence Scale of 1941

APPENDIX F

MODIFIED-MERCALLI INTENSITY SCALE OF 1931

I Not felt by people, except under especially favorable circumstances. However, dizziness or nausea may be experienced.

Sometimes birds and animals are uneasy or disturbed. Trees, structures, liquids, bodies of water may sway gently, and doors may swing very slowly.

II Felt indoors by a few people, especially on upper floors of multi-story buildings, and by sensitive or nervous persons.

As in Grade I, birds and animals are disturbed, and trees, structures, liquids and bodies of water may sway. Hanging objects swing, especially if they are delicately suspended.

III Felt indoors by several people, usually as a rapid vibration that may not be recognized as an earthquake at first. Vibration is similar to that of a light, or lightly loaded trucks, or heavy trucks some distance away. Duration may be estimated in some cases.

Movements may be appreciable on upper levels of tall structures. Standing motor cars may rock slightly.

IV Felt indoors by many, outdoors by few. Awakens a few individuals, particularly light sleepers, but frightens no one except those apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like a heavy body striking building, or the falling of heavy objects inside.

Dishes, windows and doors rattle; glassware and crockery clink and clash. Walls and house frames creak, especially if intensity is in the upper range of this grade. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeable.

V Felt indoors by practically everyone, outdoors by most people. Direction can often be estimated by those outdoors. Awakens many, or most sleepers. Frightens a few people, with slight excitement; some persons run outdoors.

Buildings tremble throughout. Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances, and a few fall. Hanging objects and doors swing generally or considerable. Pictures knock against walls, or swing out of place. Doors and shutters open or close abruptly. Pendulum clocks stop, or run fast or slow. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled open containers. Trees and bushes shake slightly.

VI Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; general excitement, and some persons run outdoors.

Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Small bells in churches and schools ring. Poorly built buildings may be damaged. Plaster falls in small amounts. Other plaster cracks somewhat. Many dishes and glasses, and a few windows break. Knick-knacks, books and pictures fall. Furniture overturns in many instances. Heavy furnishings move.

VII Frightens everyone. General alarm, and everyone runs outdoors.

People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes and streams. Water is muddied. Gravel or sand stream banks cave in. Large church bells ring. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns. Concrete irrigation ditches are considerably damaged.

VIII General fright and alarm approaches panic.

Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off (especially palm trees). Sand and mud erupts in small amounts. Flow of springs and wells is temporarily and sometimes permanently changed. Dry wells renew flow. Temperatures of spring and well waters varies. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Panel walls break away in frame structures. Decayed pilings break off. Walls fall. Solid stone walls crack and break seriously. Wet grounds and steep slopes crack to some extent. Chimneys, columns, monuments and factory stacks and towers twist and fall. Very heavy furniture moves conspicuously or overturns.

IX Panic is general.

Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings - - some collapse in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged and underground pipes sometimes break.

X Panic is general.

Ground, especially when loose and wet, cracks up to widths of several inches; fissures up to a yard in width run parallel to canal and stream banks. Landsliding is considerable from river banks and steep coasts. Sand and mud shifts horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Dangerous cracks develop in excellent brick walls. Most masonry and frame structures, and their foundations, are destroyed. Railroad rails bend slightly. Pipe lines buried in earth tear apart or are crushed endwise. Open cracks and broad wavy folds open in cement pavements and asphalt road surfaces.

XI Panic is general.

Disturbances in ground are many and widespread, varying with the ground material. Broad fissures, earth slumps, and land slips develop in soft, wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes and embankments, even at long distances. Few if any masonry structures remain standing. Supporting piers or pillars of large, well-built bridges are wrecked. Wooden bridges that "give" are less affected. Railroad rails bend greatly and some thrust endwise. Pipe lines buried in earth are put completely out of service.

XII Panic is general.

Damage is total, and practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rock falls, and slumps in river banks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

URS/BLUME

APPENDIX E

References for Part II

APPENDIX G

REFERENCES FOR PART II

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APPENDIX II

Glossary

APPENDIX H

GLOSSARY

Acceleration -- The rate of change of velocity.

Base Shear -- A shear applied to the base of a building in design or analysis to simulate the sum of the lateral forces on the building.

Base Shear Coefficient -- The ratio of the base shear to the weight of the building.

Damping -- Internal friction or resistance in a material, element, or structure that absorbs some of the energy causing vibration by converting it to heat.

Fault -- A surface or zone of rock fracture along which there has been displacement ranging from a few centimeters to a few kilometers in scale.

Focal Depth -- Depth of that point within the earth that is the center of an earthquake and the origin of its elastic waves.

Earthquake Intensity -- A measure of the effects on humans and/or structures of an earthquake at a particular place. The intensity at any point depends not only on the strength of the earthquake or the earthquake magnitude, but also on the distance from the earthquake to the epicenter and the local geology at the point.

Earthquake Magnitude -- A measure of the strength of an earthquake or the strain energy released by it as determined by seismographic observations. The concept was introduced by the seismologist C. F. Richter, who first applied it to southern California earthquakes. For that region, he defined local magnitude as the logarithm, to the base 10, of the amplitude in microns of the largest trace deflection that would be

observed on a standard torsion seismograph (static magnification = 2800, period = 0.8 sec, damping constant = 0.8) at a distance of 100 km from the epicenter. Magnitudes determined at teleseismic distances using the logarithm of the amplitude-to-period ratio of body waves are called body-wave magnitudes, and using the logarithm of the amplitude of 20-sec period, surface waves are called surface-wave magnitudes. The local body-wave and surface-wave magnitudes of an earthquake will have approximately the same numerical value.

Lateral Force -- A force applied laterally to a building in design or analysis to simulate the lateral forces of earthquake or wind.

Mean Value -- The average value obtained by dividing the sum of two or more quantities by the numbers of these quantities.

Modified Mercalli (MM) Scale -- One of the earthquake intensity scales; it has twelve divisions ranging from I (not felt by people) to XII (damage nearly total). It is a revision of the Mercalli scale made by Wood and Neumann in 1931.

Period -- The interval of time necessary for a regularly recurring motion to make a complete cycle.

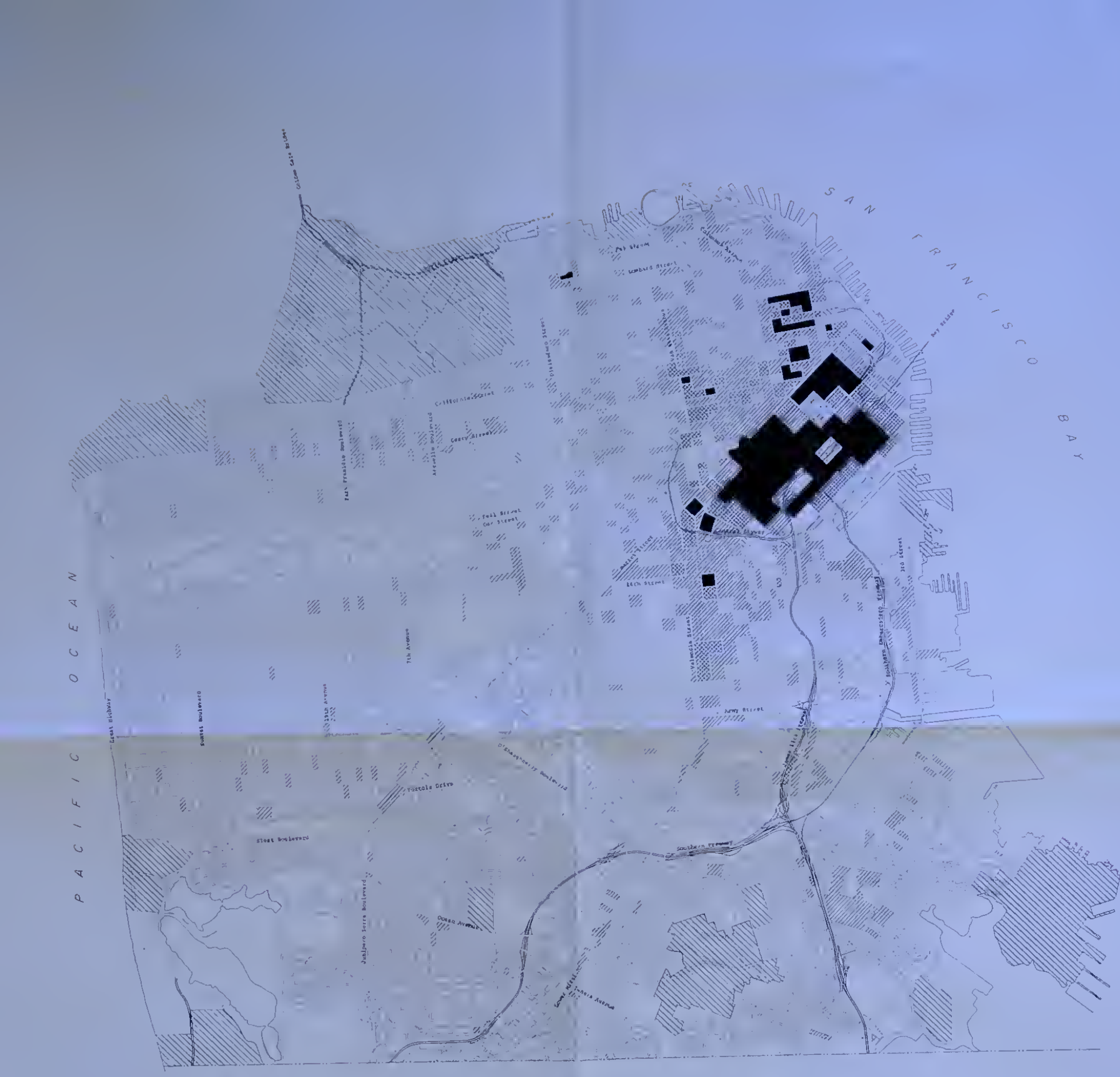
Response Spectrum -- A plot of the response of idealized single-degree-of-freedom systems of various natural periods and a constant damping value to a time history (recorded) of earthquake motion; the plot may be of acceleration, velocity, or displacement against period or frequency.

Runup -- The rush of water on land or a structure upon the breaking of a wave. The amount of runup is the vertical height above still water level that the rush of water reaches.

Uniformity Coefficient -- A numerical expression of the variety in particle sizes in mixed natural soils, defined as the ratio of the

sieve size through which 60% (by weight) of the material passes to the sieve size that allows 10% of the material to pass. It is unity for a material whose particles are all of the same size, and it increases with variety in size (as high as 30% for heterogeneous sand).

F.P. CLOTH
3



LEGEND FOR NUMBER OF PRE-CODE TYPE C NON-RESIDENTIAL BUILDINGS

- MORE THAN 10 PER BLOCK
- 6 TO 10 PER BLOCK
- 1 TO 5 PER BLOCK
- NONE
- PRESENTLY DEMOLISHED OR 10 TO BE DEMOLISHED
- INFORMATION NOT AVAILABLE OR NOT IN STUDY

NOTES

THE SOURCE OF INFORMATION IS THE CITY ASSESSOR'S RECORDS GIVING THE YEAR OF CONSTRUCTION, THE CONSTRUCTION CLASS, AND THE USE CATEGORY.

IT HAS BEEN ASSUMED THAT BUILDINGS CONSTRUCTED BEFORE 1948 ARE PRE CODE FOR THIS PURPOSE.

THE ITEM NON-RESIDENTIAL COVERS ALL USE CATEGORIES EXCEPT APARTMENTS, DWELLINGS, FLATS, DUPLEXES, FLATS AND STORES, CONDOMINIUMS, AND HOTELS OTHER THAN FIRST CLASS.

TYPE C CONSTRUCTION, FOR THIS MAP, REFERS TO BUILDINGS HAVING EXTERIOR BEARING WALLS OF MASONRY OR CONCRETE AND WOOD FLOORS AND ROOF CONSTRUCTION.

MAP SHOWING DENSITY OF PRE-CODE TYPE C NON-RESIDENTIAL BUILDINGS

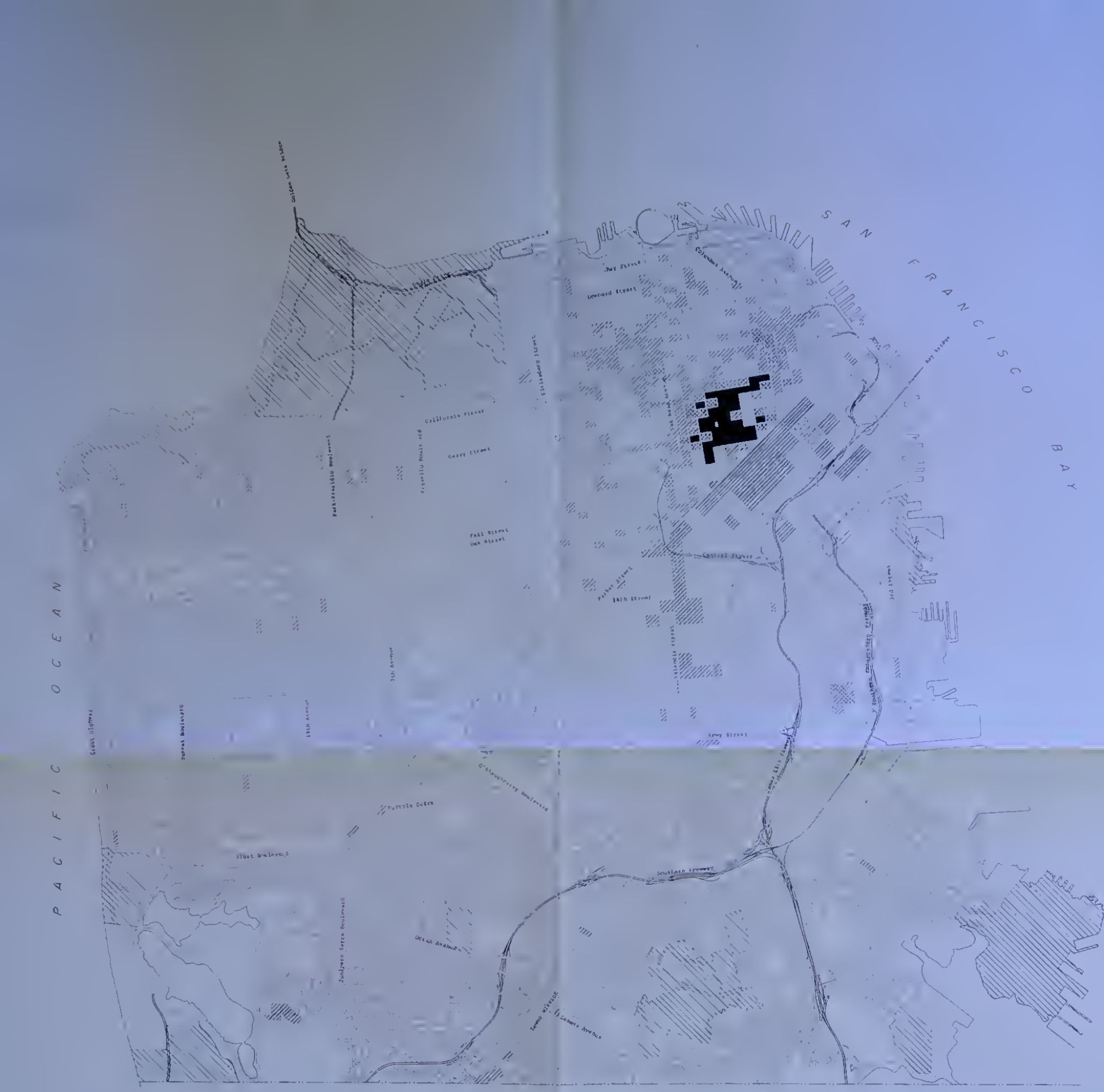
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION STRUCTURAL HAZARD EVALUATION

June 1974

by John A. Blume & Associates, Engineers

FIGURE C

REF
551.22
Sa52



LEGEND FOR LIVING UNITS IN PRE-CODE TYPE C BUILDINGS

- MORE THAN 300 PER BLOCK
- 151 TO 300 PER BLOCK
- 1 TO 150 PER BLOCK
- NONE
- RECENTLY CONSOLIDATED OR TO BE CONSOLIDATED
- INFORMATION NOT AVAILABLE OR NOT IN STUDY

NOTES

THE SOURCE OF INFORMATION IS THE CITY ASSESSOR'S RECORDS GIVING THE YEAR OF CONSTRUCTION, THE CONSTRUCTION CLASS, AND THE USE CATEGORY.

IT HAS BEEN ASSUMED THAT BUILDINGS CONSTRUCTED BEFORE 1949 ARE PRE-CODE FOR THIS PURPOSE

TYPE C CONSTRUCTION, FOR THIS MAP, REFERS TO BUILDINGS HAVING INTERIOR BEARING WALLS OF MASONRY OR CONCRETE AND WOOD FLOORS AND ROOF CONSTRUCTION.

THE NUMBER OF LIVING UNITS IS OBTAINED FROM THE CITY ASSESSOR'S RECORDS FOR BUILDINGS HAVING USE CATEGORIES OF APARTMENTS, DWELLINGS, FLATS, DUPLEXES, FLATS AND STORES, CONDOMINIUMS, AND HOTELS OTHER THAN FIRST CLASS.

2000 FEET

MAP SHOWING DENSITY OF LIVING UNITS IN PRE-CODE TYPE C BUILDINGS

SAN FRANCISCO SEISMIC SAFETY INVESTIGATION STRUCTURAL HAZARD EVALUATION

June 1974

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FIGURE B

REF
551.22
Sa52

LEGEND

- SEVERE DAMAGE
- HEAVY DAMAGE
- MODERATE DAMAGE
- SLIGHT DAMAGE
- RESIDUAL DAMAGE NOTED OR TO BE DEVELOPED
- INFORMATION NOT AVAILABLE OR NOT IN STUDY

NOTES

ESTIMATED DAMAGE LEVELS ARE PLOTTED ON A BLOCK-AVERAGE BASIS FOR BUILDINGS EXISTING IN DECEMBER 1973. THE AVERAGE FOR EACH BLOCK WAS COMPUTED FROM DAMAGE ESTIMATES FOR EACH BUILDING WEIGHTED ACCORDING TO THE NUMBER OF STORIES.

IN NO CASE SHOULD DAMAGE INTENSITY DATA BE APPLIED TO INDIVIDUAL BUILDINGS FOR WHICH DAMAGE CAN BE ESTIMATED ONLY BY SPECIFIC ANALYSIS. NO SPECIFIC ANALYSIS OF ANY BUILDING HAS BEEN CONDUCTED IN OR FOR THIS INVESTIGATION. THE BUILDING DATA USED ARE THOSE OBTAINED FROM THE CITY ASSESSOR'S RECORDS AND THE ESTIMATION OF DAMAGE HAS BEEN BY APPROPRIATE, STATISTICALLY BASED METHODS. DATA ON LARGE AREAS BY 100 ACREAGE OR STATISTICAL USES, ARE EXPECTED TO BE MEANINGFUL FOR OVERALL PLANNING AND RELATED PURPOSES.

GROUND MOTION AND BUILDING RESISTANCE TO GROUND MOTION ARE HIGHLY RANDOM VARIABLES OFTEN WITH EXTENSIVE VARIATIONS EVEN UNDER AVERAGE CONDITIONS. THE DATA IN FIGURE A ARE FOR AVERAGE CONDITIONS, AND FACILITIES OR LOCATIONS IN EITHER DIRECTION CAN BE EXPECTED IN ANY LOCAL AREA.

0 2000 FEET

MAP SHOWING ESTIMATED BUILDING DAMAGE LEVELS FOR A "1906-TYPE" EARTHQUAKE

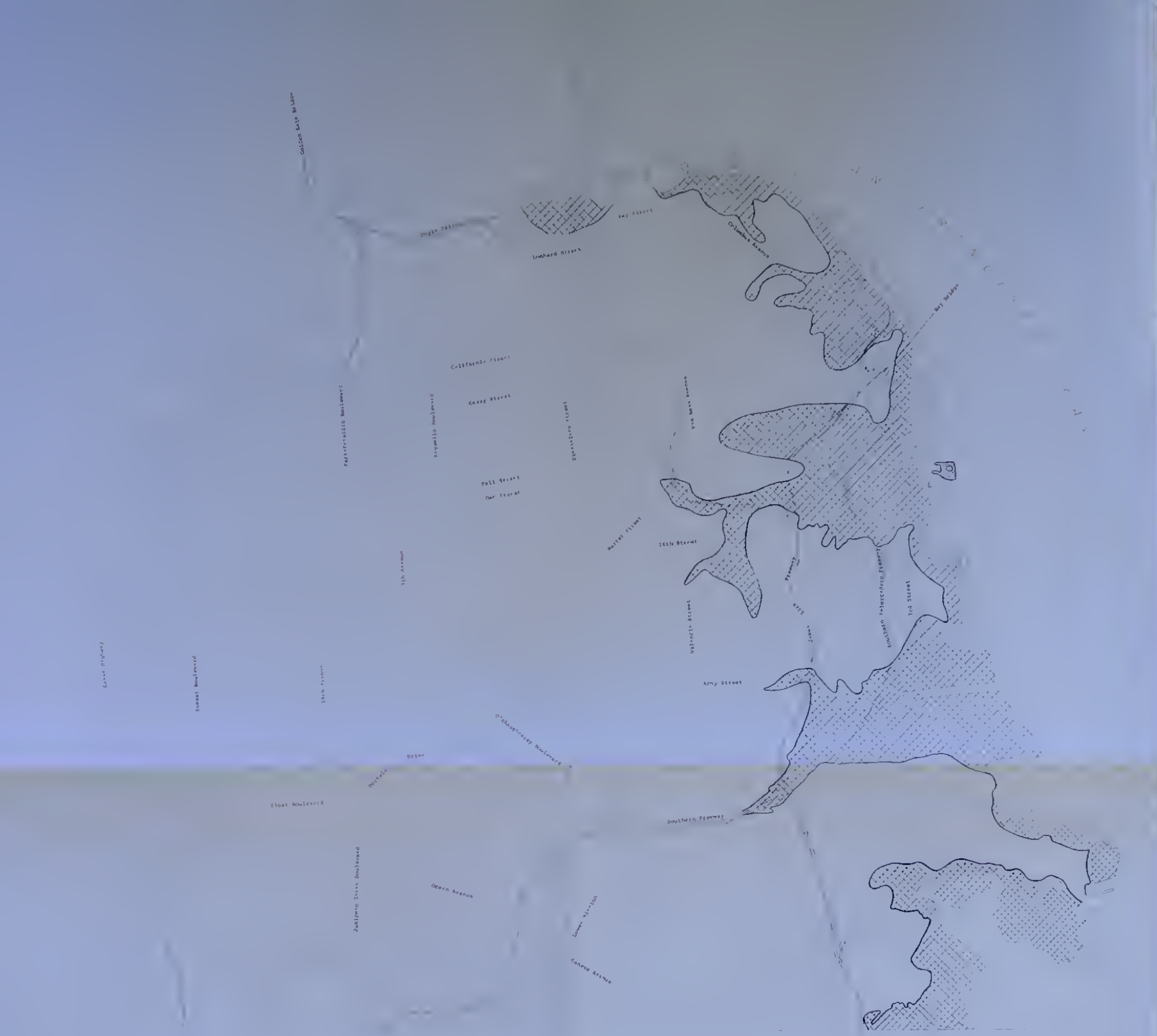
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION STRUCTURAL HAZARD EVALUATION

JUNE 1974

by John A. Blume & Associates, Engineers

FIGURE A

REF
551.22
Sa52



AREAS OF MAJOR POTENTIAL SUBSIDENCE HAZARD

SAN FRANCISCO SEISMIC SAFETY INVESTIGATION GEOLOGIC EVALUATION

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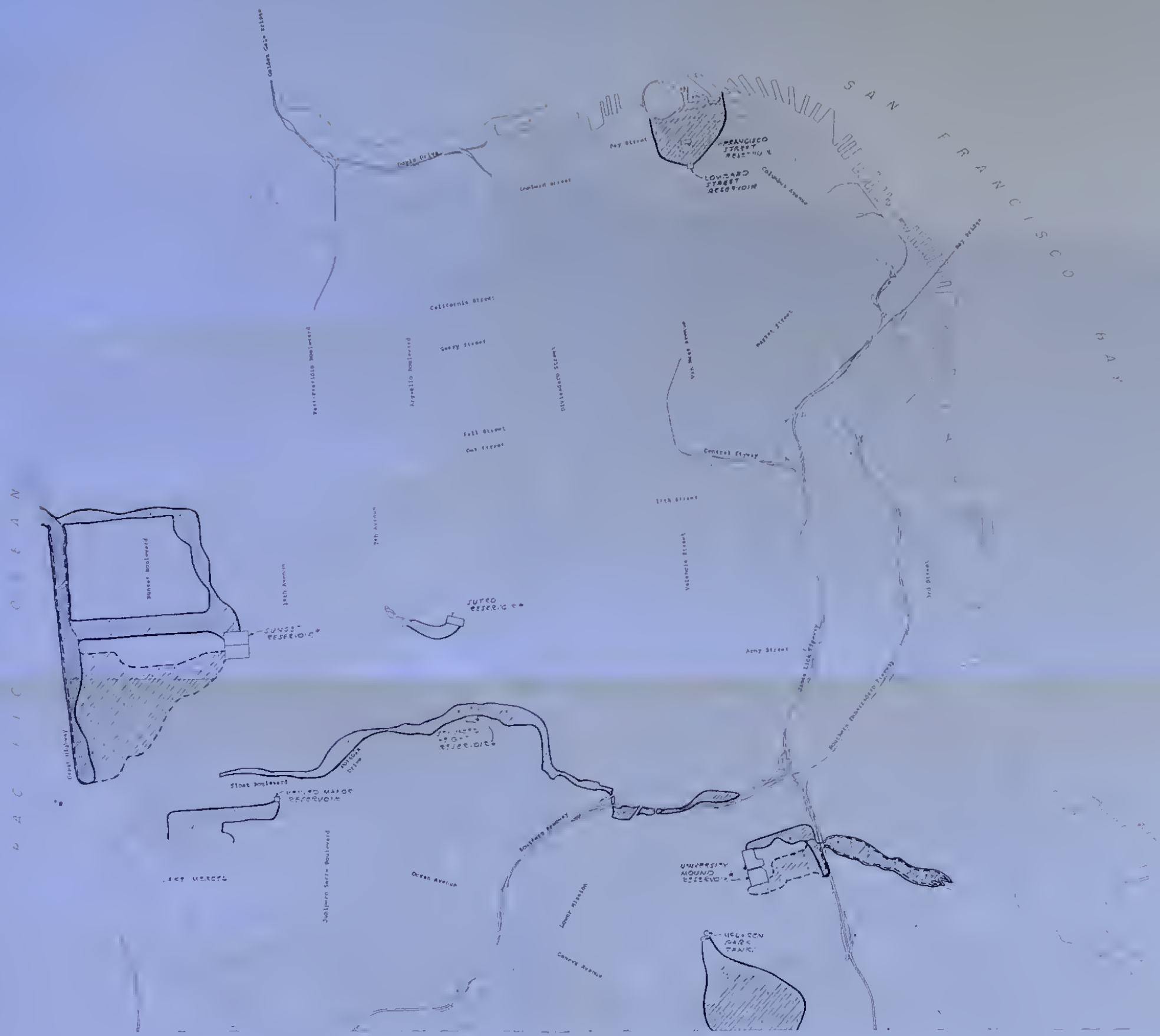
FIGURE 10

REF
551.22
Sa52



INUNDATION AREAS DUE TO RESERVOIR FAILURE

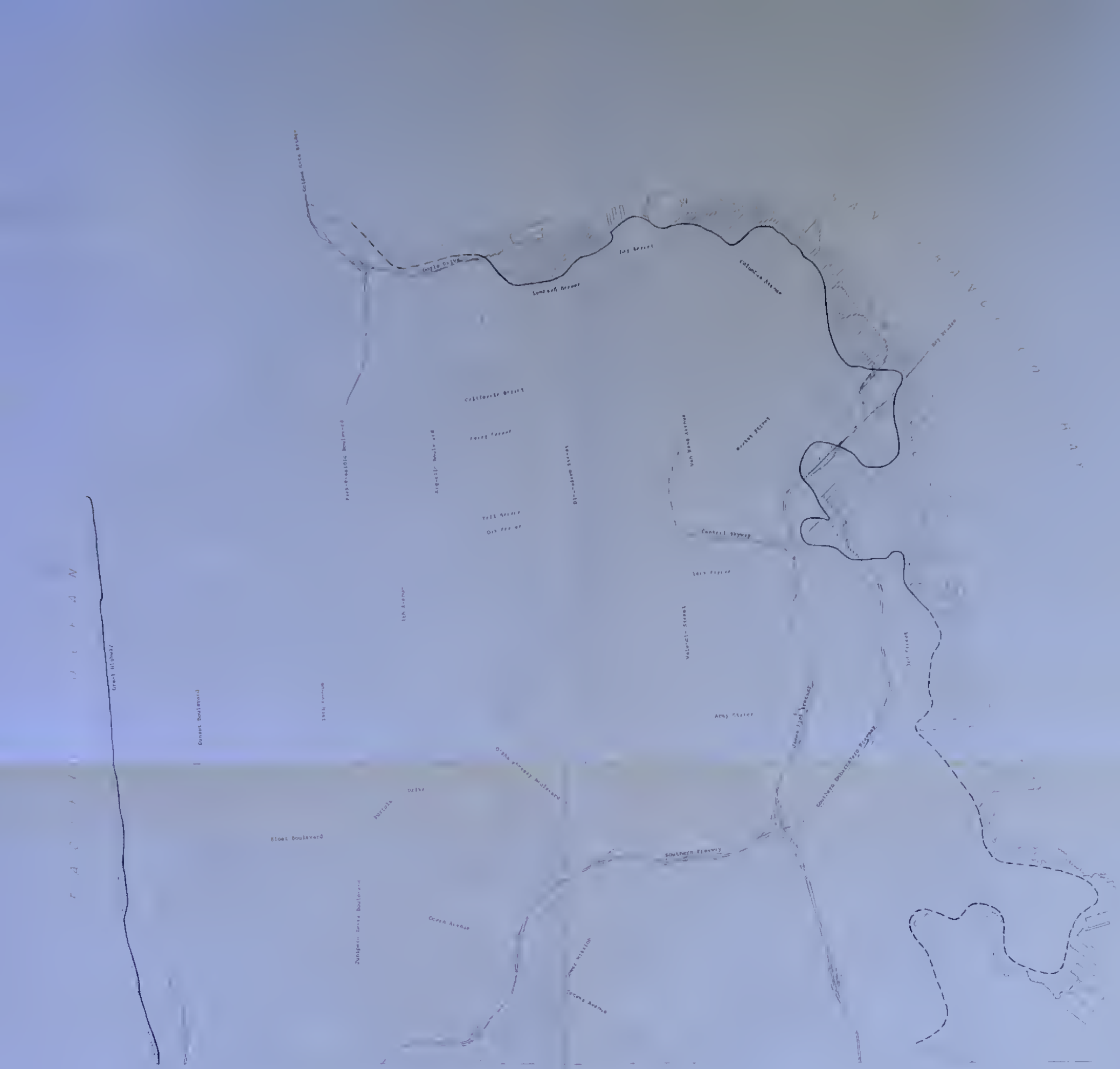
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION
GEOLOGIC EVALUATION

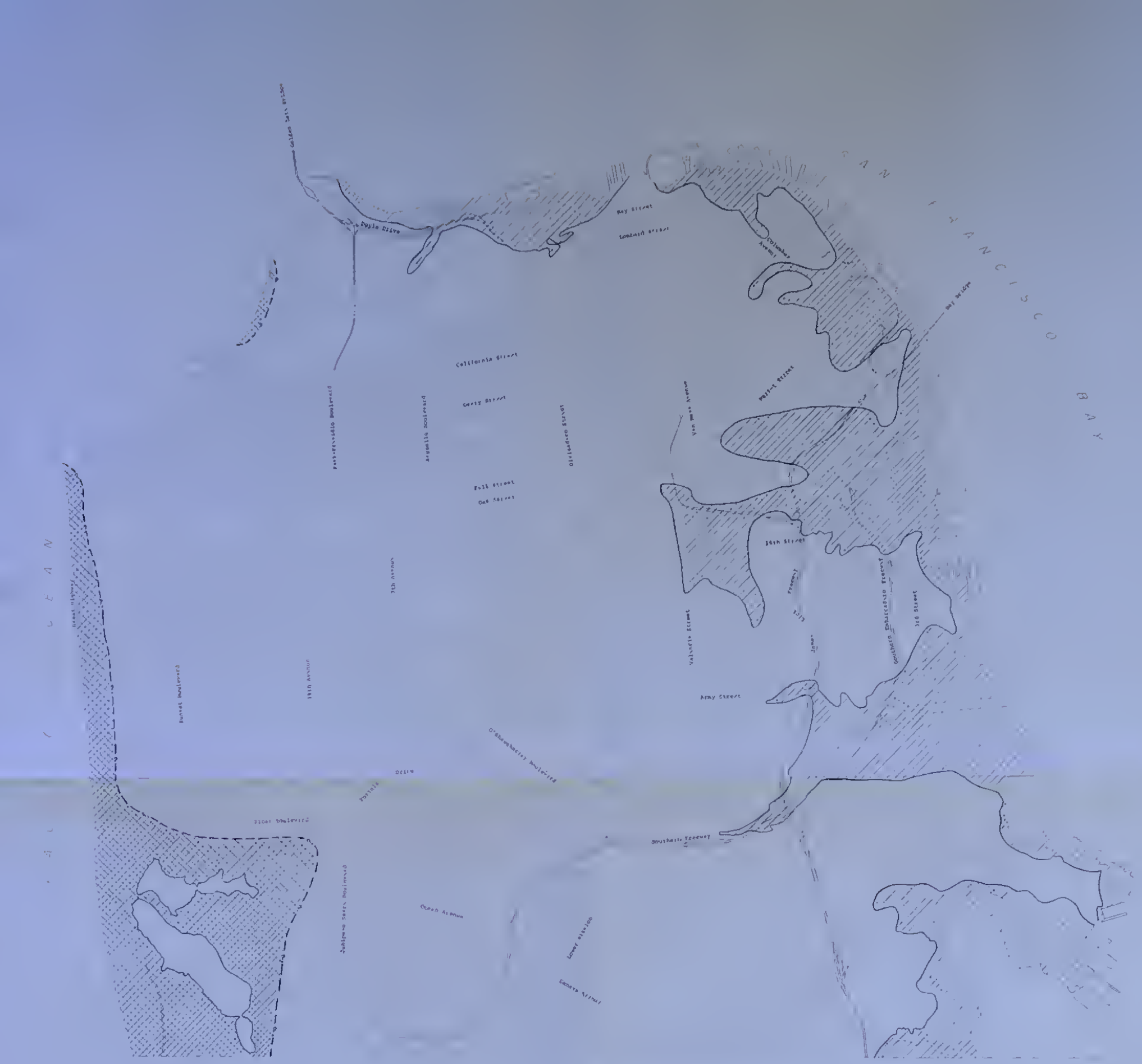
June 1974

by John A. Blume & Associates, Engineers

FIGURE 9

REF
551.22
Sa52


Great Highway
Sloat Boulevard
Ocean Avenue
Junipero Serra Boulevard
Lake Merced
Skyline Boulevard
Lake Merced
Chabot Terrace
Lake Merced
Valencia Street
Army Street
Southern Freeway
3rd Street
Bay Shore
Van Ness Avenue
Market Street
Central Skyway



EXPLANATION

Area of liquefaction potential

Area of probable liquefaction potential

2000 FEET

AREAS OF MAJOR POTENTIAL LIQUEFACTION HAZARD

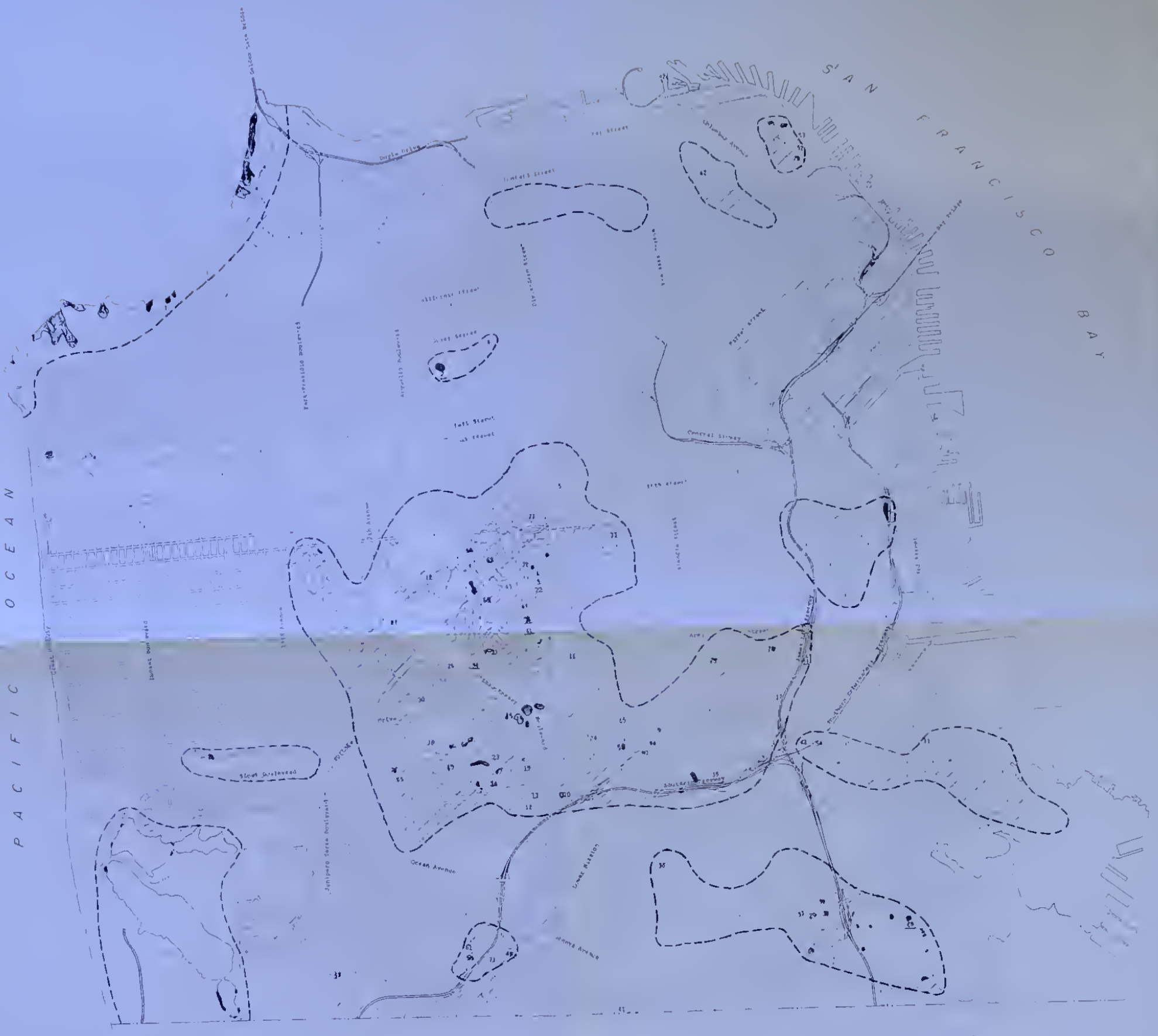
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION GEOLOGIC EVALUATION

June 1974

by John A. Blume & Associates, Engineers

FIGURE 5

REF
551.22
Sa52


PACIFIC OCEAN
SAN FRANCISCO BAY
Ocean Avenue
Lower Alemany
Alemany Avenue
Junipero Serra Boulevard
Slight Slide Area
Outline of slide area
Location of slide. Identified by number in files of the City of San Francisco, Bureau of Building Inspection. Those underlined are active slides
Areas of potential landslide hazard
2000 FEET

EXPLANATION

LANDSLIDE LOCATIONS

SAN FRANCISCO SEISMIC SAFETY INVESTIGATION
GEOLOGIC EVALUATION

June 1974

by John A. Blume & Associates, Engineers
(from Bonilla, 1971, and Schlocker, et al., 1958, and City of San Francisco, Bureau of Building Inspection)

FIGURE 4

REF
551.22
Sa52

EXPLANATION

A Very violent. Cristing and shearing of rock masses. Deep and extended fissuring in soil, many large landslides and rockfalls

B Violent. Totally general collapse of brick and frame structures when not unusually strong. Serious settling of better buildings. Lateral displacement of streets, bending of rails and ground fissuring.

C Very strong. Masonry badly cracked with occasional collapse. Frame buildings lurched when on east underpinning with occasional collapse.

D Strong. General but not universal fall of brick chimneys. Cracks in masonry and brick work.

E Weak. Occasional fall of brick chimneys and plaster.

NOTE: Intensities are given for earthquake similar to the 1906 event in magnitude and proximity to San Francisco.

2000 FEET

ESTIMATED INTENSITY OF FUTURE GROUND SHAKING

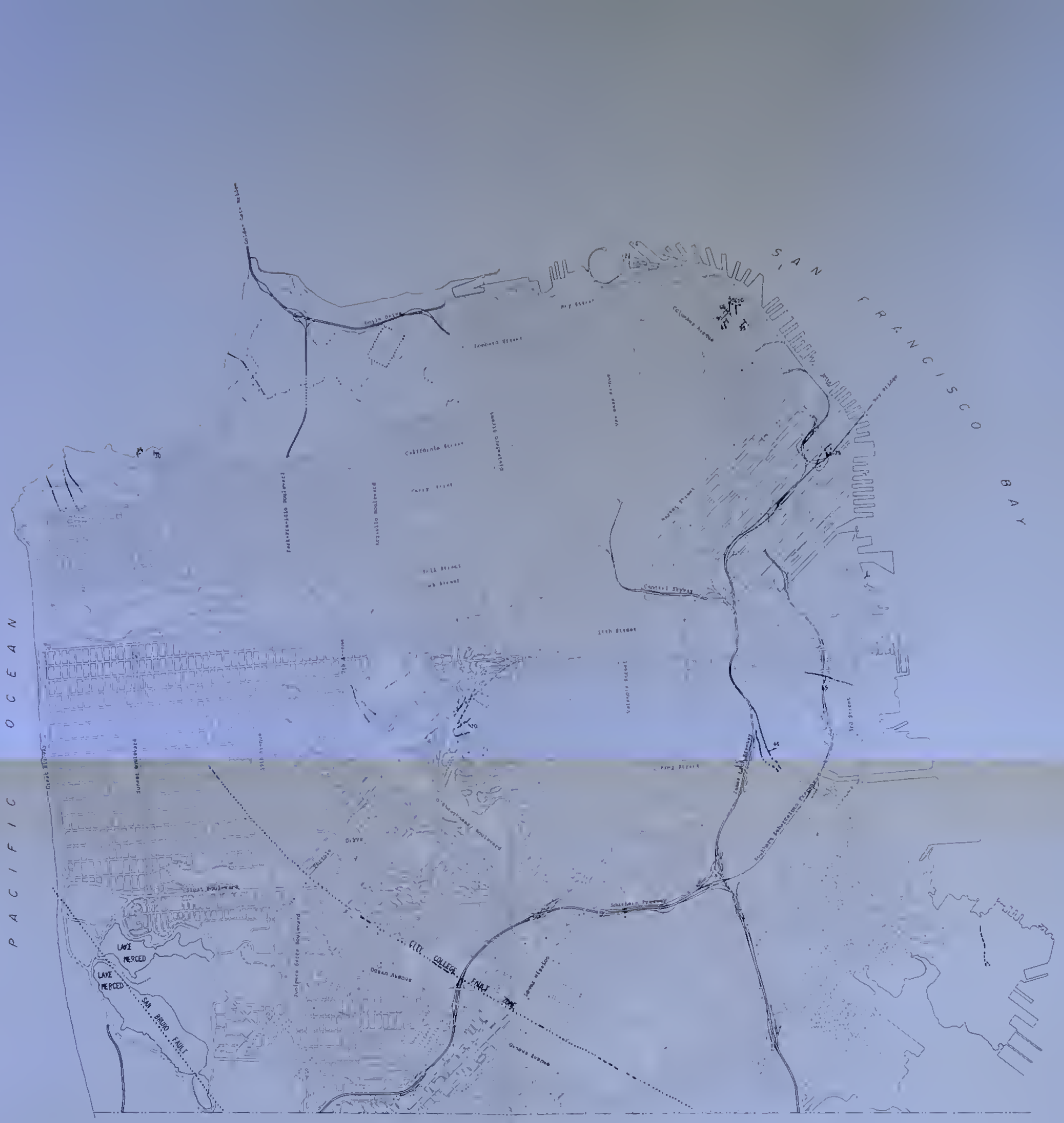
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION
GEOLOGIC EVALUATION

June 1974

by John A. Blume & Associates, Engineers
(Modified after Wood, H. O., 1908)

FIGURE 3

REF
551.22
Sa52



EXPLANATION

Fault showing dip or angle of inclination
Dashed where approximately located, dotted where buried. Zone are known to be active

2000 FEET

MAP SHOWING FAULT LOCATIONS

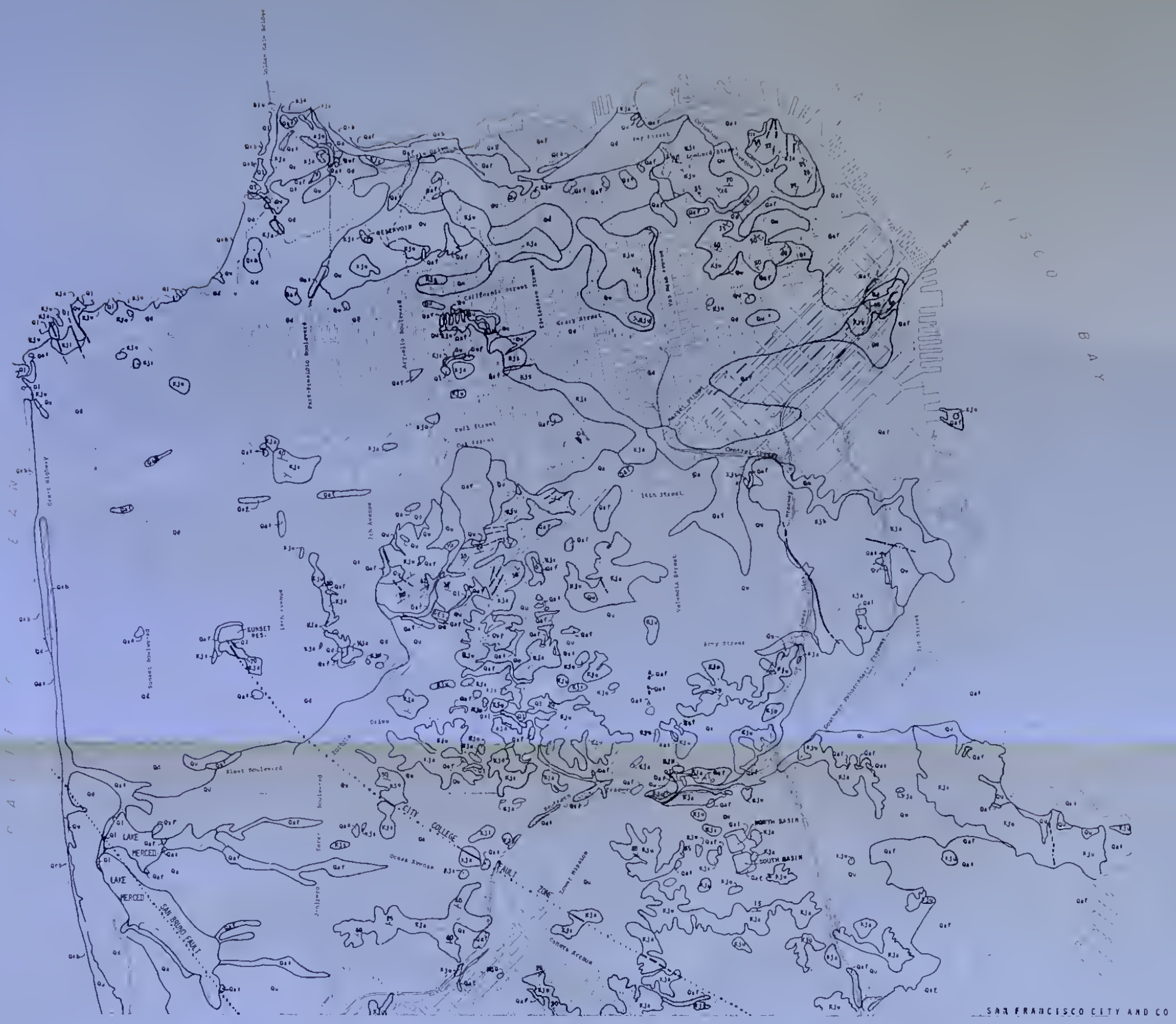
SAN FRANCISCO SEISMIC SAFETY INVESTIGATION
GEOLOGIC EVALUATION

June 1974

By John A. Blume & Associates, Engineers
(from Bonilla, 1971, and Schlocker, et al., 1958)

FIGURE 2

REF
551.22
Sa52


SUNSET RES.
LAKE MERCED
LAKE MERCED
SAN BRUNO FAULT
CITY COLLEGE
FAULT
NORTH BASIN
SOUTH BASIN
Geary Street
Fulton Street
Lincoln Way
Sloat Boulevard
Sunset Boulevard
19th Avenue
Ocean Avenue
Junipero Serra Boulevard
Arguello Boulevard
Presidio Boulevard
California Street
Clement Street